Strategic Investment and Entry Decisions for Soybean Breeding in western Canada

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Abstract

With the increase in soybean adoption in western Canada, accompanied by the lack of private soybean breeding, begs the question whether the levy funded Saskatchewan Pulse Growers (SPG) should invest in a producer-controlled breeding program at the Crop Development Center (CDC). SPG has very successful breeding programs with other pulse crops, but with soybeans, the decision to invest has unidentified economic impacts due to the potential private involvement.

This thesis examines the crowding effects and welfare effects from the SPG investing in a soybean breeding program in western Canada. The thesis presents three models of strategic investment and entry to analyze private incentives to invest in soybean breeding and the effects of breeding investment on welfare. Players for each game include the Saskatchewan Pulse Growers (SPG) and private soybean seed companies located in western Canada.

The first model is an extensive form game where SPG's decision to investment is followed by the private firm. This model examines the potential holdup problem in soybean breeding in western Canada, which can exist if a private firm expects *ex post* entry by SPG. The extensive form game shows that the private firm has an incentive to invest when the threat of SPG entry is low, and/or their payoff increases because of SPG entry. SPG does not deter private entry when they credibly select traits that do not compete with the private firm, or traits that result in large research spillovers from SPG to the private firm.

The second model is a two-stage game for investment in soybean breeding. This model examines how the degree of substitutability and the difference in the level of existing seed technology impact private profits, farmer welfare, and social welfare. In the first stage of the game, SPG and the private firm set their level of investment. The second stage of the game each player sets their level of quantity. Results of the two-stage game show that the private firm is crowded out when SPG invests in biotech traits and has a competitive level of existing seed technology. SPG can reduce crowding effects by either investing less prior to entry, which lowers their level of existing seed technology, or by selecting food edible traits that are less substitutable with private firm soybean varieties.

The third model is a simulation model. The simulation model estimates the impact investment in soybean breeding has on economic surplus in western Canada for 20 years. The

simulation model quantifies these effects using a new production function, data on yield, acres, costs, and acreage elasticities. The simulation model also quantifies how the degree of substitutability impacts the net present value of private profits, farmer welfare, and social welfare. The results of the simulation model are consistent with the two-stage game in that increased substitutability lowers a private firm's incentive to invest in soybean breeding. However, SPG can reduce crowding effects by either selecting traits that are less substitutable with private soybeans, increasing their price of seed, and/or lowering their level of investment.

SPG's decision to invest in a soybean breeding program has the potential to provide farmers in western Canada with a maximum net present value benefit of 9 billion dollars over twenty years. However, outcomes that benefit farmers the most are likely to crowd out any significant private investment. The consensus of the three models is that SPG has breeding and pricing options that will limit the detrimental effect on private investment in soybean breeding while still increasing farmer welfare in western Canada. However, any option to reduce crowding effects of SPG comes at a cost of farmer welfare.

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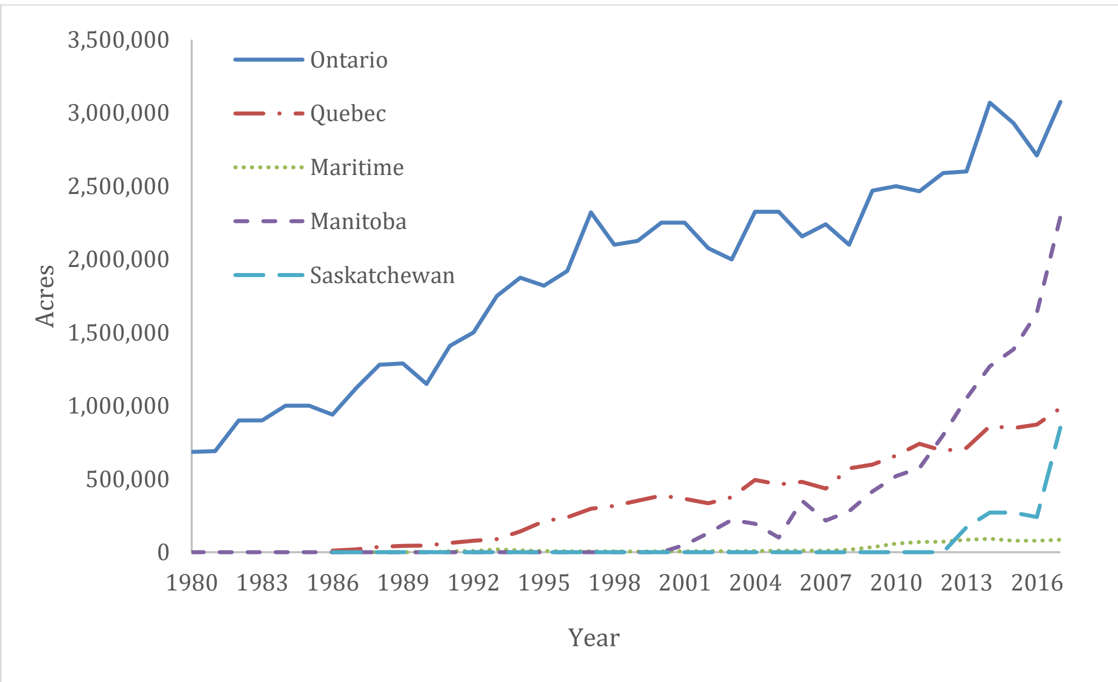
Chapter 1 Introduction

1.0 Motivation

In Canada, soybean adoption has been rapidly increasing. More specifically, soybean production in Manitoba and Saskatchewan has increased by 1.9 million acres in the past five years from 2013 where 1.2 million acres were seeded (Statistics Canada, 2017a). Soybeans are becoming a major crop in Canada's agricultural sector, they are grown in both Manitoba, Saskatchewan, and the southern regions of Ontario and Quebec. This is shown in figure 1.0.

Figure 1.0: Soybean Production in Metric Tonnes by Province in Canada (1980-2017)[a]



Source: Statistics Canada (2017a)
[a] CANSIM Table 001-0017

In Saskatchewan, maturity plays a key role in the producer's decision to adopt soybeans. The short growing season in the prairies has a negative impact on yield, which makes growing soybeans a risky choice for farmers. Research projects funded by the public sector and producer-controlled organizations seek to improve the maturity of soybean varieties grown in western Canada. Genetic research has identified eight earliness loci that affect maturity and flowering (Cober and Morrison, 2010). Current research at Soyagen Genome Canada builds on this research improving the yield and disease resistance for early maturing soybean varieties (Richardson, 2017). If successful, these varieties will be better suited for northern climates, provided that the shorter photoperiod sensitivity would reach full maturity in Saskatchewan (Richardson, 2017).

Despite the recent industry growth and the potential for future growth based on better genetics, there are no public or private soybean breeding programs located in western Canada. This lack of investment will limit yield improvement making it more difficult for farmers to capitalize on the rotational and agronomic benefits in growing soybeans. It is also important in the adoption process that farmers have adequate knowledge on new varieties with better genetics and higher yield (Richardson, 2017). Providing growers with new varieties is important, however, information on how to grow varieties that are well suited for northern climates is an important feat in successfully marketing this innovative seed technology.

1.1 Problem Statement

In western Canada, breeder seed for soybeans originates from breeding labs in Glyndon Minnesota, Grand Forks North Dakota, Ottawa Ontario and Arva Ontario (Heal, 2017; Lee, 2017). Currently, there are no breeding programs in western Canada even with the significant growth in seeded acres. The Crop Development Center (CDC) and SPG have the option to create a joint venture that invests in a soybean breeding program and distribution channels to market seed royalty free to farmers across the prairies.

Growers in western Canada have adopted private soybean varieties and depend on the private market to invest and develop better varieties. Despite the private market’s presence in the seed market, they have no soybean breeders in western Canada (Mascarenhas, 2017). They also charge a high price for soybean seed (Basol, and Lenssen, 2012; Heal, 2017), which limits adoption and grower returns.

Given the industry’s current reliance on the private seed industry, SPG must consider the crowding effects of any investment strategy. In eastern Canada, both private and public firms take part in funding soybean breeding programs (Soy 20/20, 2013). Public firms such as Agriculture and Agri Food Canada (AAFC) invest in breeding conventional soybeans, while private firms breed both biotech and conventional varieties (Soy 20/20, 2013). If SPG decides to invest in a breeding program at the CDC, the crowding effects could have negative implications on economic welfare in western Canada.

1.3 Goal and Objectives

The goal of this thesis is to examine the economic impact of SPG investing in a soybean breeding program in western Canada. More specifically, this thesis examines the impact SPG investment has on economic welfare and potential crowding effects. This thesis uses three models to examine crowding and welfare effects. Three models are needed to understand the change in investment strategies when firms consider specific factors and criterion for entry in soybean breeding. The extensive form game examines how investment and entry decisions change with a holdup problem and spillover effects. The two-stage game is needed to understand how substitutability and the existing level of seed technology impact investment decisions. This game examines the crowding effects and welfare implications from SPG and private investment in soybean breeding under different levels of substitutability and existing seed technology. The third model, simulation model, examines how investment decisions change under the net present value investment criterion. The simulation model uses data to estimate the long-term economic impacts and crowding effects over 20 years of breeding investment. Results from each model provide important policy implications for investment and entry decisions in soybean breeding. These three models contrast each other in showing that different criterion for investment and entry lead to various welfare implications.

1.4 Thesis Overview and Organization

The organization of the thesis now follows from chapter 2 to 6. Chapter 2, *Background*, covers topics related to the northward genetic advancement of soybeans, the Saskatchewan Pulse Growers, and funding mechanisms for soybean breeding. The background also discusses measures of market failures in breeding; the role of public and producer funded breeders play in addressing market failures; crowding in and out; and the role of cooperatives in innovation. Chapter 3, *Theoretical Model of Strategic Investment and Entry*, explains the methodology in extensive form game theory and presents a simple game of entry in soybean breeding. Chapter 4, *The Two-Stage Game*, examines the crowding effects between SPG and private investment in soybean breeding. This chapter also examines how SPG's trait selection can limit the crowding out of private investment. Chapter 5, *Simulation Model*, quantifies the long-term impacts of breeding investment over 20 years. The model uses data on yield, acres, price, costs, and elasticities to estimate private profits, farmer welfare and social welfare. This chapter uses a sensitivity analysis to examine how substitutability, spillover effects, price, and investment impact SPG and private market investment decisions. Chapter 6, *Conclusions*, provides a thesis summary, policy implications, research limitations and further research.

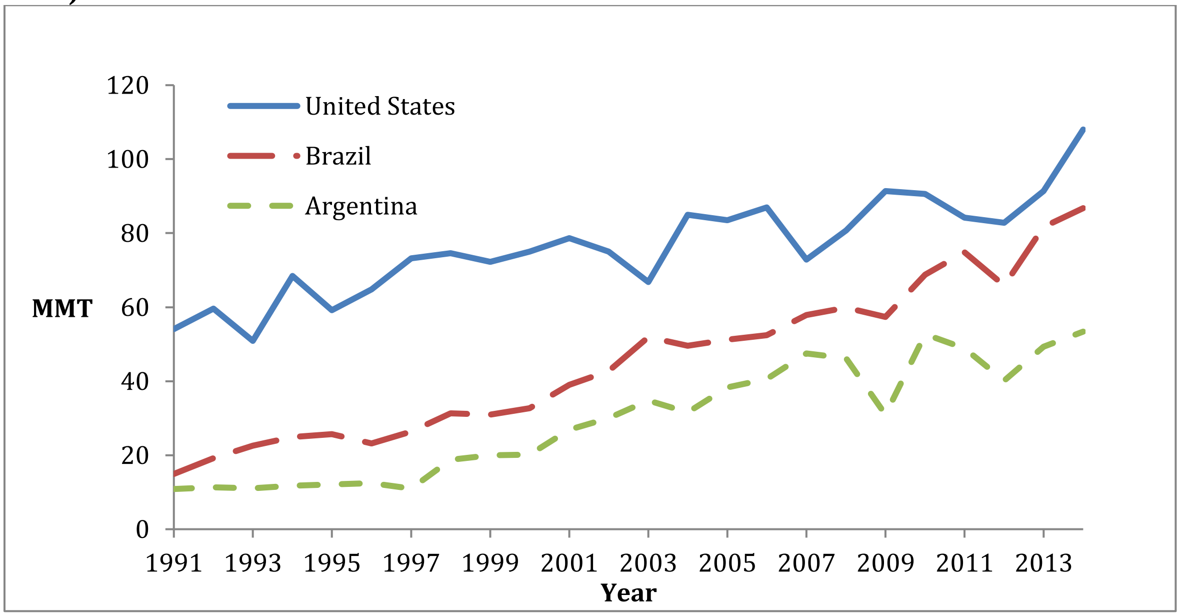
Chapter 2 Background

2.0 Soybean Production and Genetic Advancement Northward

Today, the major soybean exporters in the world include the United States, Brazil, Argentina, Uruguay, Paraguay, and Canada. Figures 2.0 and 2.1 shows soybean production within these countries from 1991 to 2014. Notably, soybean production has increased in northern latitudinal countries, such as Canada, the United States and countries within Europe.

In Canada, public institutions like Genome Canada fund projects in which their research goal is sequencing genomes for several species. The Soyagen project is funded by Genome Canada and focuses on sequencing the soybean genome. This project involves deep probing into genetics and identifies DNA markers that control maturity and resistance to disease (Genome Canada, 2015). The Soyagen team is using these markers to develop new soybean varieties that are more suitable to western Canada's shorter growing season.

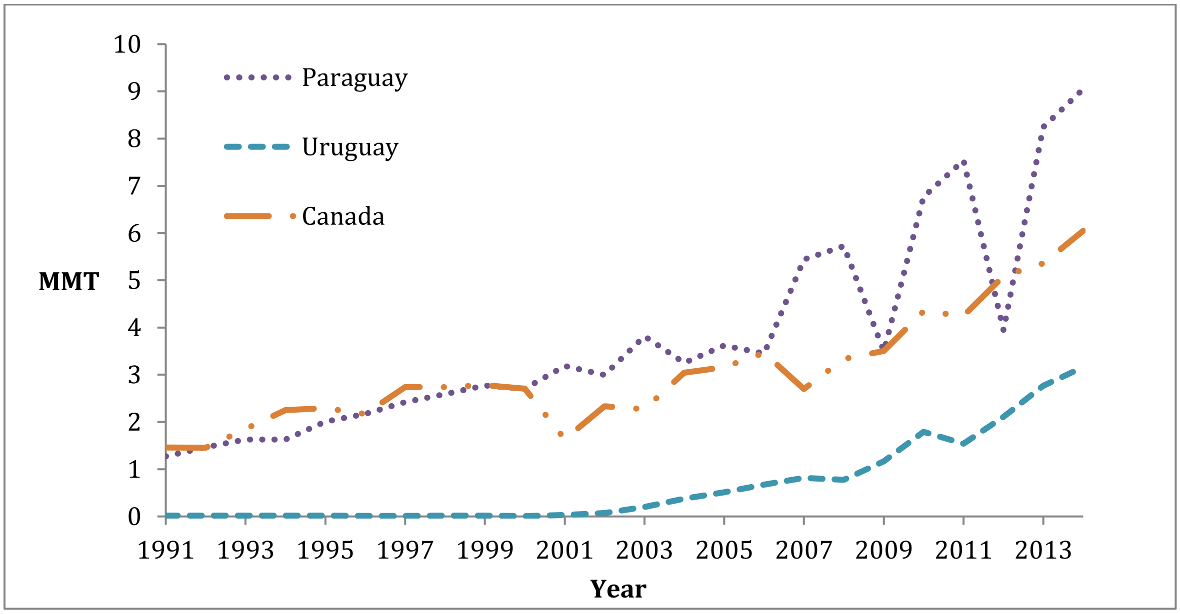
Figure 2.0: Total Soybean Production in the United States, Brazil, and Argentina (1991-2014)[a]



Source: Food and Agricultural Organization of the United Nations (2016)

[a] A production unit is in Million Metric Tonnes (MMT)

Figure 2.1: Total Soybean Production in the Paraguay, Uruguay, and Canada (1991-2014)[a]



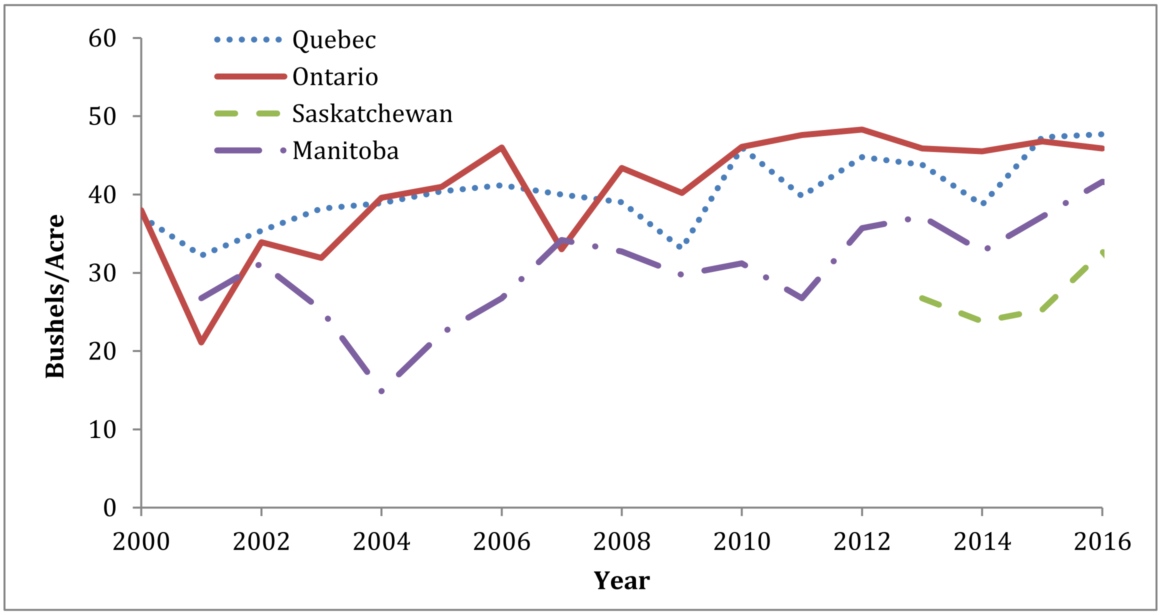
Source: Food and Agricultural Organization of the United Nations (2016)
[a] A production unit is in Million Metric Tonnes (MMT)

Current soybean breeding is largely focused on increasing maturity, protein content, and yield (Soy Canada, 2016a). This goal is difficult due to the tradeoffs between maturity, yield and protein. Genetics advancements in soybean breeding have been able to reduce these tradeoffs, but at a marginal rate.

In western Canada, maturity is a significant yield limiting factor that occurs in both wet and dry years. The private industry currently has 24 short-season soybean varieties available to producers in Saskatchewan, however, there remains to be no dedicated breeding program for soybeans in western Canada (Richardson, 2017). The market incentive to develop better short-season soybean varieties is to increase the tonnage of soybeans crushed (Soy Canada, 2016a). However, the yield for these varieties is deemed to be much lower than later maturing varieties.

Figure 2.2 shows the yield for soybeans in Ontario, Quebec, Manitoba, and Saskatchewan. Ontario and Quebec have greater yields when compared to Manitoba and Saskatchewan because of its longer maturing season. However, soybean yields in Manitoba have been trending upwards since 2001.

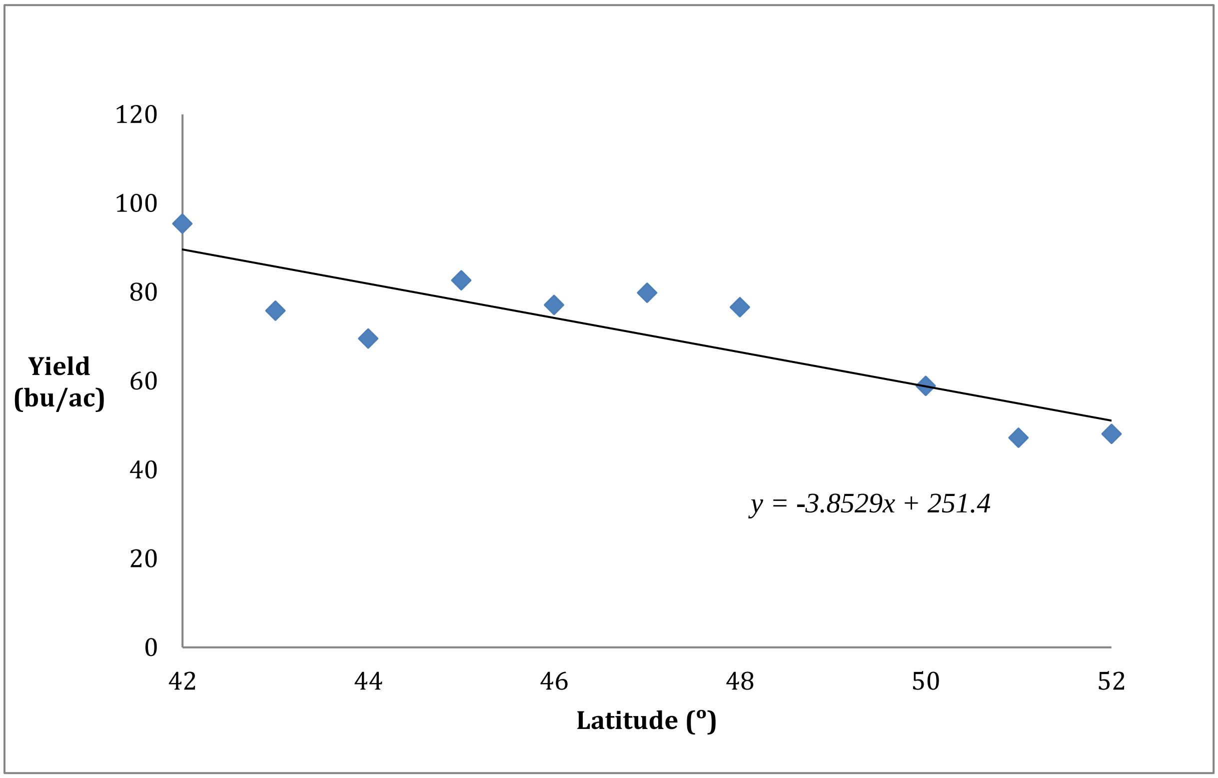
Figure 2.2: Annual Average Yield of Soybeans in Ontario, Quebec[a], Manitoba, and Saskatchewan[b]



Source: Statistics Canada (2017a; 2017b)
[a] CANSIM Table 001-0072
[b] CANSIM Table 001-0017

Because of the required earlier and shorter flowering period for soybeans at higher latitudes, genetic differences can be identified spatially amongst different varieties. Figure 5 explains that the yield potential for longer-maturing soybeans in lower latitudes is much greater than the yield potential of shorter-maturing soybeans at higher latitudes. Soybean yield in Ontario and North Dakota can reach 60 bushels per acre while yields in Manitoba and Saskatchewan range up to 40 bushels per acre in trials. The trendline in figure 2.3 shows the relationship between yield and latitude, which is negative. Current research in soybean breeding aims to increase the yield of shorter-maturing varieties and flatten the slope of this trendline.

Figure 2.3: Roundup Ready Soybean Yield Potential for Varieties in Trial[a,b,c] with respect to Latitude[d]



Source: Adapted from Manitoba Pulse and Soybean Growers (2016a) North Dakota State University (2016), Ontario Soybean and Canola Committee (2016). Sask Seed Guide (2017).

[a] Trails for Ontario are from the Ontario Soybean and Canola Committee's RR Performance in Ontario Study

[b] Trails in North Dakota are from the NDSU combined RR soybean fee test

[c] Manitoba and Saskatchewan trials are from the pulse and soybean variety evaluation guide and seed guide

[d] Latitudes are based on the location of trial site

2.1 Saskatchewan Pulse Growers

The Saskatchewan Pulse Growers (SPG) Development Board is a levy-funded producer-controlled organization formed in 1983 that exists to support research and development in Saskatchewan (Saskatchewan Pulse Growers, 2016a). Through the AgriFood Act, SPG claims a 1% levy from pulse and soybean buyers who must be registered with SPG (Gray and Bolek, 2011). Unlike other Saskatchewan producer-controlled organizations, which are commissions, SPG is the only organization with non-refundable levies. SPG is governed by a Board of Directors (BOD) containing seven members that are elected every three years. These directors are elected to direct SPG in funding research projects that focus on issues and topics applicable to pulse growers throughout Saskatchewan. More specifically, SPG's BODs work on the evaluation and approval of funding research projects and maintaining checkoff expenditures.

SPG's funding model examines the overall value research applicants provide to producers and the pulse industry. SPG is involved in a wide range of activities including research projects, producer communications and workshops. These activities include the CDC's development program, select seed growers program, and domestic and international market development programs such as funding Pulse Canada (Gray and Bolek, 2011).

2.1.0 SPG's Involvement in Pulse Breeding

The CDC's pulse breeding program is funded by SPG. Although the CDC is the owner of the varieties bred, SPG has exclusive rights to market and distribute CDC varieties under their select seed growers program. The program offers select-status growers in Alberta, Saskatchewan, and Manitoba royalty free foundation seed (Saskatchewan Pulse Growers, 2017b). This means that growers do not have to pay a levy to the seed distributor when they sell seed to producers. SPG funds this program through the checkoff levies they collect on production sales. For specific types of lentils and niche markets the SPG's tender release program gives certain companies the exclusive right to sell seed to growers in which they receive a royalty on the seed (Saskatchewan Pulse Growers, 2017b).

Recently, SPG has allowed SeCan and Seednet to distribute CDC pulse varieties outside of Saskatchewan. Gray and Bolek (2011) explain that SPG also provides private firms with an incentive to develop new markets in providing companies the exclusive right to sell CDC varieties to foreign countries, in return for a royalty. SPG is also involved in research collaborations that are funded by the pulse science cluster. The pulse science cluster is affiliated with AAFC's Growing Forward framework and funds large-scale research projects for pulses. Overall, SPG maintains a highly effective innovation system that can gain cooperation from government, private companies, and growers, which benefits the agricultural sector in western Canada.

2.1.1 SPG's Role in Soybeans

Although SPG has contributed to pulse breeding, agronomic issues, and demand promotion, their current focus in soybeans has been limited to genomic research, agronomics and grower extension. With the increase in soybean production in Saskatchewan, SPG is informing producers on how to grow soybeans through workshops and seminars to stimulate adoption. Information is mostly on agronomic factors, which include seeding rates, fertilizer, inoculant, treatment, chemical, and disease management. Because SPG supports the breeding and distribution of other pulses bred by the CDC, the development board plans to conduct a market study on soybeans in Saskatchewan before they decide to breed a variety of their own. Today, SPG's role in soybean varietal development is:

> "SPG is currently assessing the soybean variety development landscape to understand what role if any SPG should play in the soybean variety development space. Unlike other pulses such as lentil and chickpea (where SPG provides significant support for pulse crop breeding), soybean variety development and release for Saskatchewan is undertaken significantly by small and large multinational corporations. When this exercise is complete, SPG will decide on the best strategy for the pulse and soybean growers of the province." (Mascarenhas, 2017)

SPG receives a 1% levy on the sale of soybeans (Saskatchewan Pulse Growers, 2016b). While much of this levy is directed to agronomic research, a sizable portion goes to genetic improvement. SPG has a total of $275,000 invested in research for genetic improvement in soybeans (Saskatchewan Pulse Growers, 2017a). The current amount of SPG funding contributed to the Soyagen project is $115,000 dollars. Notably, SPG does not hold the rights to the variety lines being developed within the Soyagen project.

2.1.2 Mechanisms for Funding Breeding and the Role of IPRs

At the CDC, check-off levies have been the largest contributor to the development of new pulse varieties in Saskatchewan. Apart from check-off levies, which are used for facilitating agricultural research and development across many commodity groups, other legal mechanisms are in place to fund plant breeding programs.

These mechanisms are known as Intellectual Property Rights (IPRs) and provide private firms with an economic incentive to invest in plant breeding. There are several types of IPRs that may be used to collect royalties on licensed seed. IPRs in the agricultural sector include Plant Breeders' Rights (PBR), hybrids, Technology Use Agreements (TUA), and Closed Loop Marketing Agreements (CLMA) (Pidskalny, 2017).

A limitation of many IPRs is that producers can save and/or brown bag seed, which reduces royalty income, making it difficult for the private sector to successfully fund breeding programs. Brown bagging occurs when another producer illegally purchases licensed seed from other producers (Plant Breeders' Rights, 2016). CLMAs and TUAs are considered attractive

IPRs in collecting royalties on the sale of seed. CLMAs restrict the buyer to sell their entire production quantity to a specific buyer (i.e. Warburtons). TUAs can legally force producers to sell all their production and require that seed is not reused for planting in the future (i.e. Monstanto). TUAs are only enforceable under utility patents, which in Canada can only be issued for GM crops. CLMAs do not require a patent, but are often difficult to enforce. SPG maintains funding for pulse breeding at the CDC through checkoff levies, instead of relying on royalties to fund the pulse breeding program.

In other countries, alternative royalty collection systems are in place to fund breeding programs. In Australia and France, End Point Royalty (EPR) systems have been implemented, which is a royalty collected on the sale of production. In Brazil, importers currently have a large-scale TUA with Monsanto and DuPont for Intacta RR2 Pro Technology soybeans (St. Louis and Wilmington, 2016). The goal of these systems is to provide public institutions and private companies an incentive to fund breeding programs and foster innovation in the agricultural sector.

2.1.3 Current soybean breeding and the seed industry

2.1.3.0 United States

In the United States, soybean breeding programs are funded by similar value capture mechanisms as in Canada. Entities can file PBRs through UPOV 91 and utility patents through the Plant Variety Protection Act. The vast majority of breeding programs in the United States are funded by utility patents. Ninety percent of the utility patents on cultivars in the United States are issued for corn and soybeans (Fuglie et al, 2011). As of 1997, 70-90 percent of soybean acres consisted of private sector varieties (United States Department of Agriculture, 2004).

The United Soybean Board (USB) and Qualified State Soybean Boards (QSSBs) are also a significant source, of largely upstream, breeding effort. These Boards are established via a federal marketing order that mandates a collection of 1% checkoff on the sales of soybeans, with proceeds being equally split between the two levels. The USB invests in genomics, breeding, agronomic research, and market development programs that are facilitated by QSSBs. USB checkoffs fund many breeding programs that already have outside support in laboratories, field sites and staff (United Soybean Board, 2017). Currently, the USB is funding soybean breeding programs that enhance protein content without reducing yield and oil content. However, many of these breeding programs are dedicated to pre-commercialization and focus on germplasm development. These property rights to these variety lines are either sold or given to private companies for commercialization.

In the 1950s, through state-level voluntary programs soybean producers joined together to increase profitability by investment schemes in research and demand promotion (Williams, Capps, and Lee, 2014). The national soybean checkoff program was implemented in the 1990 Farm Bill where industry levies began to be collected nationally by the USB. The USB has invested 1.38 billion dollars in soybean research, promotion, and communications since 1970/71. Since the national program, and the creation of the USB, checkoff expenditure in soybean research from 1992/93 to 1998/99 has tripled in the United States.

Since the 1996 Farm Bill, evaluations of the effectiveness of commodity programs are mandatory every five years. The 2012/13 evaluation study finds that without a checkoff program, additional profits earned by soybean producers would not be as high as they are today (Williams, Capps, and Lee, 2014). A Benefit-Cost Ratio (BCR) shows that from 1980/81 to 2012/13 additional profits to farmers with the check-off program are 6.5 dollars for every checkoff dollar spent between this time period (Williams, Capps, and Lee, 2014). The benefits from the check-off program includes a bigger U.S. soybean industry, larger export markets, and reduced competitive threat from the South American soybean industry. The study states that failure to maintain soybean checkoff expenditures (for even one year) would reduce producer profits in future years.

2.1.3.1 Eastern Canada

The current soybean breeding and seed industry in eastern Canada has a similar structure to the US where public and private markets can both fund soybean research. The large presence of food-grade soybeans in eastern Canada provides a premium to soybean growers that seed conventional varieties. These growers usually have a CLMA with their seed company/manufacturer when growing conventional varieties that are food grade. While the ability to crush biotech and conventional varieties provides growers with marketing flexibility, the coexistence of conventional and biotech varieties mitigates price risk when the demand for crush or food-edible soybeans is reduced. In some years, food-edible soybeans can acquire up to 35% of the market share in Ontario and 50% in Quebec (Soy 20/20, 2013).

In eastern Canada, most soybean breeding programs are publicly funded through AAFC with some being funded through checkoff levies, PBRs, CLMAs and/or TUAs. Again, the private market focuses more on capturing value through patents or CLMAs, while public programs may be funded by checkoff levies collected by Soy Canada. Soy Canada collects five cents per tonne levy from growers on the sale of production and two cents per tonne from soybean crushers (Minogue, 2015a). However, soybean crushers only pay a maximum of 20,000 dollars when they exceed a million tonnes of crush per year. Soybean exporters and seed companies also pay tiered fees up to 20,000 dollars a year to Soy Canada. Importantly, the two major public soybean breeders in eastern Canada are Agriculture and AgriFood Canada and the University of Guelph.

2.1.3.2 Western Canada

The soybean seed industry in western Canada is primarily served by large multinational corporations (Mascarenhas, 2017). These corporations directly sell seed and some claim a royalty from TUAs, while producer-controlled organizations collect a checkoff levy on the sale of soybean production. Unlike the pulse sector, farmers are paying a relatively high price for soybean seed, which provides an incentive for private research and development for new short-season varieties. In western Canada, there are currently three producer-controlled organizations that represent soybean growers and collect checkoff levies. These organizations include the Manitoba Pulse and Soybean Growers (MSPG), Alberta Pulse Growers (APG), and SPG.

In 1983, the MPSG formed as a group of bean growers in efforts to access support from the Agricultural Stabilization Act (Manitoba Pulse and Soybean Growers, 2016b). At the time, the government was unwilling to work with individual producers in providing support, but instead was willing to work with an organization. MPSG was incorporated in 1984 with eleven founding directors. During this time MPSG had no-funds (accounting and clerical duties were supported by Manitoba Agriculture) until they began to collect checkoff levies through the Agriculture Producers Funding Organization Act in 1989 (Manitoba Pulse and Soybean Growers, 2016b).

MPSG is currently funded by a 0.5% checkoff levy that represents 3,500 pulse growers (Minogue, 2015b). In 2015, MPSG allocated 60% of their board budget of approximately 1.1 million dollars to research projects (Manitoba Pulse and Soybean Growers, 2017). MPSG currently funds soybean research projects that explore genetic improvement, on-farm management and agronomic issues. Genetic research is largely in collaboration with AAFC researchers in efforts to improve disease resistance and maturity of short-season varieties in western Canada.

The Alberta Pulse Growers (APG) represents pulse and soybean growers in Alberta funded by a 1% checkoff levy on production sales (Minogue, 2015b). Since a large portion of growers in Alberta seed peas, APG research investments for peas span genetic, yield, and health objectives. However, research contributions to soybean development in Alberta are much different in comparison to Saskatchewan and Manitoba. Alberta has decided to invest in research projects that identify genotypes to improve soybean yield in southern Alberta (Alberta Pulse Growers, 2017). Due to the lack of moisture in southern Alberta, research is specific to irrigation farms attempting to achieve a yield of 60 bushels per acre. Two studies by Manjula Bandara on soybean genetics are funded by APG looking at improving soybean competitiveness and cost-effectiveness in southern Alberta (Alberta Pulse Growers, 2017).

SPG is the final producer-controlled organization in western Canada and represents pulse and soybean growers in Saskatchewan. They collect a one percent levy on all pulses and soybeans grown in Saskatchewan. In soybeans, investment has been limited for SPG, but will continue to grow with the expanded adoption of soybeans in Saskatchewan.

2.2 Measures of economic surplus and market failures in crop breeding

This section discusses the nature of market failures in the soybean industry in western Canada and how producer-controlled organization can correct these failures by investing in research. The section also discusses how spillover effects might be able to provide private firms with incentives to invest in research even when competing against subsidized research. The section concludes with a discussion on cooperatives and how their role in innovation differs from producer-controlled organizations.

In a perfectly competitive market, under the restrictive assumptions where there are no efficiency losses, an efficient allocation of resources, and no additional gains from exchange, economic surplus is maximized (Frank, Parker, and Alger, 2013). In a market where these restrictions apply and there is monopolistic pricing, this creates a deadweight loss and reduces welfare. However, in a dynamic model, where firms can invest in research and development, patents, and the monopolistic power they provide, can improve welfare.

In the soybean industry, a large majority of seed is patented and priced monopolistically in competition with other patented soybean varieties. In this setting, market power reduces the incentive to invest in breeding because a share of the quality improvement is captured by downstream industry (Malla and Gray, 2005). This effect is worsened when some varieties are developed without patents. Conventional varieties only acquire short-term property rights through PBRs, which reduces seed prices and increases the downstream spillovers, further reducing the incentive to invest (Shi, Chavas, and Steigert, 2010). Notably, SPG's seed growers program distributes other pulse seed to farmers royalty free, which if implemented in soybeans would provide strong price competition for private breeders.

2.2.0 The role of private, producer and public plant breeding in addressing market failures

In the presence of market failures caused by monopolistic pricing of soybean seed, farmers end up paying a significant share of the rents and market inefficiencies get passed down the supply chain in the form of input and output prices. The role private, producer and public funded plant breeders play in addressing these market failures is to invest in research that makes seed available to farmers royalty free. Funding breeders also reduces the lack of investment that occurs when property rights are not strong.

If private companies attempt to invest in conventional varieties, brown-bagging and farm saved seed would play against the collection of royalties on certified seed that are enforced by PBRs. In many cases, producers can readily save and/or brown bag conventional seed, making royalty collection for breeders difficult. In extreme cases, brown bagging and farm saved seed can result in unprofitable breeding programs. Depending on a breeder's ability to commit to a future pricing scheme and whether farmers are myopic (unable to recognize future prices), Perrin and Fulginiti (2009) explain in a stylized model that breeders may have very little incentive to enter markets where only PBRs are permitted because farm saved seed limits them to 11-69% of marginal social welfare benefit.

Because SPG already invests in pulse breeding at the CDC, they are a suitable example of a producer-controlled organization that addresses market failures caused by the lack of investment in breeding and research. SPG initially began to invest in pulse breeding due to the lack of private investment in the pulse industry. Notably, the private industry has made little effort to enter the pulse industry as they would be competing against subsidized research.

As a producer-controlled organization, SPG addresses market failures by investing in research that would otherwise not be invested in by the private market due to the low returns on investment. Private firms would not survive investing in the pulse sector as they are unable cover their cost of developing a technological advancement that gives them an increasing returns to scale production function (Fulton, 1997). This is because they are unable to patent pulse crops, as they would lose international markets if they did so, and do not possess enough market power with PBRs. Government has been involved in addressing these failures, but producers have been able to provide additional resources through funding research at the discretion of producer-controlled organizations.

In some cases, private breeders can invest in this type of research to address these market failures; however, their incentive to invest is much lower than for producer and public funded breeders. Therefore, producer and public breeders must be aware of these market failures when allocating funds to research projects.

2.2.1 Crowding in and crowding out

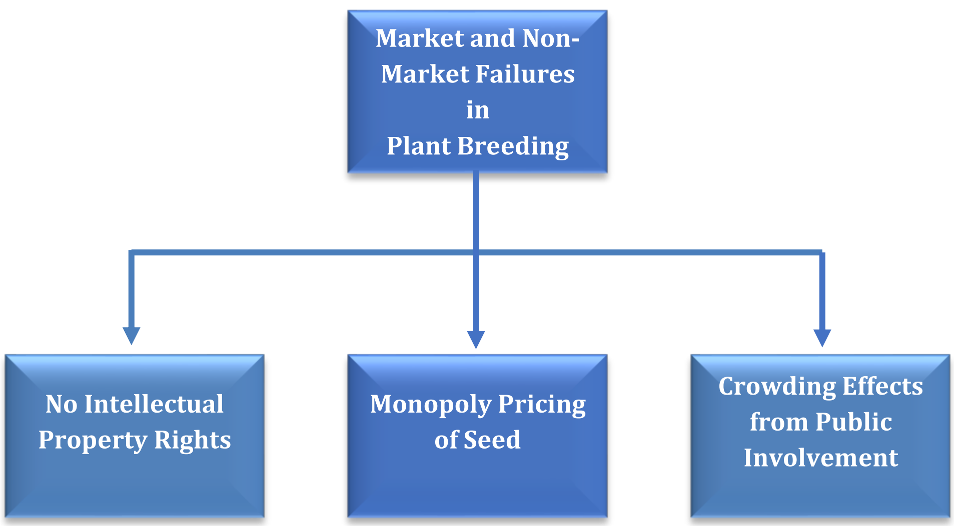
The implications of investing in research publicly has been politicized by many economists (Wolf, 1979). However, not considered by many of these economists is that government funded research may have spillover and crowding effects that would "crowd in" the private market and increase social welfare (Gray, Malla, and Tran, 2006). Notably, the private market may be disincentivized to invest in research because of government involvement. In this case, public investment is said to "crowd out" the private market. Malla and Gray (2005) find that basic research (i.e. scientific knowledge) in the canola sector "crowds in" the private market, while applied research (i.e. product development) "crowds out" the private market.

Importantly, without technology spillovers from the public research, the private sector is likely to get crowded out when attempting to compete with subsidized research. However, investments in breeding made by the government, under certain circumstances, may spur private investment crowding in the private market. If there are large spillover effects, public investment is likely to improve economic surplus in providing the private market with new products at a zero marginal production cost. As stated by Fulton (1997), if the public market provides the private sector with knowledge that is non-rival and non-excludable, private firms in theory are more likely to price closer to marginal cost when using these inputs. Gray, Malla, and Tran (2006) explain that spillovers from public research steer private research and marketing towards social interests, resulting in more productive private firms. With large research spillovers, private firms should benefit from products created by the public sector.

The problem that arises in this case is the public market may not be able to provide the socially optimum amount of research, which causes a non-market failure (Fulton, 1997). In this case, the private market needs to acquire intellectual property rights to correct such non-market failures. Given this theory, it is still uncertain whether SPG investment in soybean breeding would “crowd out” the private market and needs thorough economic examination.

To summarize, Figure 2.4 shows the three types of market and non-market failures in the plant breeding sector. Market and non-market failures in plant breeding can arise from the lack of intellectual property rights, monopoly pricing of seed, and crowding effects from public involvement.

Figure 2.4: Three Types of Market and Non-Market Failures in the Plant Breeding Sector



Source: Author

2.2.2 Cooperative Role in Innovation

In this section, we provide a brief literature review on cooperatives and how their role in innovation compares to a producer-controlled organization. Giannakas and Fulton (2005) explain that cooperatives are much different than regular businesses because customers/members of the cooperative can also be the owners of the business. In an agricultural setting, this means that farmers who purchase fertilizer and chemical from a cooperative agribusiness may also be the owners of that business. The purpose of having a customer owned business lets the members of the cooperative directly influence business goals and operations. Because of this, cooperatives typically maximize member welfare by either returning profits to their members, or by investing retained earnings in infrastructure (Fulton and Giannakas, 2001). Because producer-controlled organizations represent farmers, and invest levy dollars to maximize farmer welfare, their actions to some extent can be compared to a cooperative. Examining the effect cooperatives have on price and innovation from literature provides important insights on how a producer-controlled organization's involvement in soybean breeding could impact price and innovation in western Canada.

Giannakas and Fulton (2005) examine the impact a cooperative firm has on economic welfare when competing against an Investor Owned Firm (IOF) on price and innovation. The game assumes heterogeneity amongst consumers who purchase from either the cooperative firm or IOF. Results show that when there is low heterogeneity and similar innovation costs, both the cooperative and IOF have little incentive to innovate. When there is large heterogeneity and low innovation costs for the cooperative, there is greater total innovation activity. Giannakas and Fulton (2005) also show that by just having cooperative presence in the market benefits farmers even when innovation efforts fall. This is because prices are set lower when the IOF competes with a cooperative firm. For a producer-controlled organization seeking to invest in soybean breeding that would compete against private firms, literature suggests that heterogeneity and pricing has a large impact on total welfare and total innovation efforts. We examine these concepts for producer-controlled organizations in further detail throughout the rest of this thesis.

The next chapter discusses the impact of entry in monopolistically competitive markets, game theory, and a private firm's incentive to invest in soybean breeding when research spillovers exist.

Chapter 3 Theoretical Model of Strategic Investment and Entry

3.0 Introduction

As mentioned in chapter one, despite the significant growth in soybean acres and the apparent potential for future soybean production in western Canada, the private sector has yet to establish a soybean breeding program north of the Upper Midwest U.S. border. At the same time, SPG, who collects a levy for research and has a successful pulse breeding program, have yet to fund a program for soybean breeding. In this chapter, we explore this lack of committed investment by either party using economic theory related to the *hold-up problem* as a plausible explanation for this outcome. We show that a hold-up problem can plausibly exist depending on the payoff matrix for SPG and the private sector. In Chapter 4, we build on this framework by exploring how product substitutability and SPG's pricing behavior can change breeding payoffs.

This chapter begins with a brief overview of the theory of monopolistic competition, which is needed to examine strategic investment and entry in soybean breeding. This is followed with an extensive form game where SPG and a private firm choose whether to make the sunk cost of investing in a soybean breeding program. Within the extensive form game, we explain the scenarios that would lead to a hold-up problem and crowding out of the private firm. The section ends with a discussion on how a private firm's incentive to invest in a soybean breeding program is influenced by SPG's investment strategy.

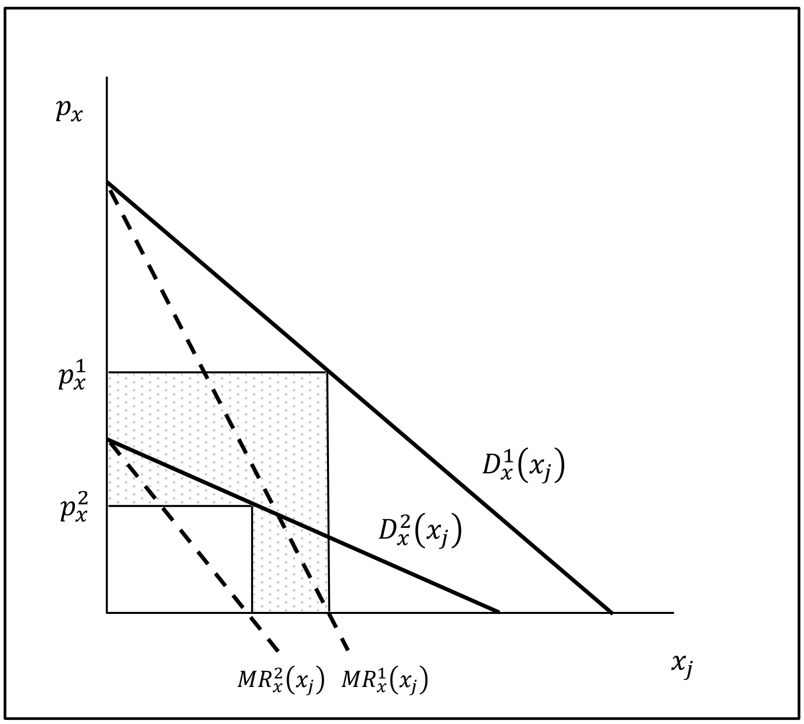
3.1 Monopolistic Competition

In economics, partial equilibrium models usually assume that all products sold in the market are homogenous. However, in the case of monopolistic competition, firms can produce differentiated products at a sunk cost and sell their product at a monopolistic price (Binger and Hoffman, 1988).

The model of monopolistic competition represents markets in which entry is limited due to factors such as patents, increasing returns to scale, and geographic isolation (Binger and Hoffman, 1988). Each of these factors are present in soybean breeding, making the model of monopolistic competition an appropriate comparison when modelling strategic investment and entry decisions.

Under monopolistic competition, as firms enter the market with new products, the demand for existing products decreases (Binger and Hoffman, 1988). When an incumbent firm enters the market with a differentiated product, the demand for existing products generally decreases and may also become more elastic. Figure 3.0 shows this effect on the demand curve in which there is a rotation counter-clockwise and a shift to the left upon entry. When a new product enters the market, the market share and price of other products tends to decrease, reducing the profits of incumbent firms (as illustrated by the dotted area in Figure 3.0). While entry increases competition and lowers prices closer to marginal cost, monopolistic competition may still be far from being perfectly competitive. Because there are fixed costs involved in the production and sale of a new product, market prices have to exceed marginal costs by enough to cover these fixed costs. In a symmetric equilibrium, profits are positive, but will be negative if another firm enters the market. The market power is dependent on the degree of product differentiation and fixed costs per product. In the case of new plant varieties, the royalty stream has to be large enough to support the cost of variety breeding and development.

Figure 3.0: The Effect of Entry on an Existing Firm under Monopolistic Competition



Source: Adapted from Binger and Hoffman (1988)

Importantly, in monopolistically competitive markets, there is assumed to be economies of scale. The reason for a firm to have economies of scale is due to the large fixed costs that are acquired in producing a certain commodity. Dixit and Stiglitz (1977) explain that firms will produce a commodity if the sum of their revenues, minus variable costs, covers their fixed cost.

In a competitive market, producing such a commodity would result in negative profits when marginal cost is equated to the demand price. Therefore, a monopolistic component, where prices exceed marginal cost, result in positive profits and production of a commodity.

3.2 Extensive Form Game Theory

Game theory is a branch of economics that has also been used to model firm entry. The standard assumptions in a symmetric game is that each player acts in self interest and anticipates other players to do the same. The most well-known game in game theory is the prisoner's dilemma. The prisoner's dilemma is known as a simultaneous game, since both criminals decide whether to confess or remain silent in the same time period. In other games, decisions can either be made simultaneously or sequentially. When decisions are made sequentially, the game is often referred to as an extensive form game, meaning that players act in a sequence. The important feature in extensive form games is that players can observe their rival's action. Extensive form games are often referred to as dynamic games because time is a factor or variable. These games must have a finite number of players, actions, nodes, and end set of actions and nodes (Jehle and Reny, 2011). Nodes are points at which a player must make their decision and can lead to another node or a specific outcome.

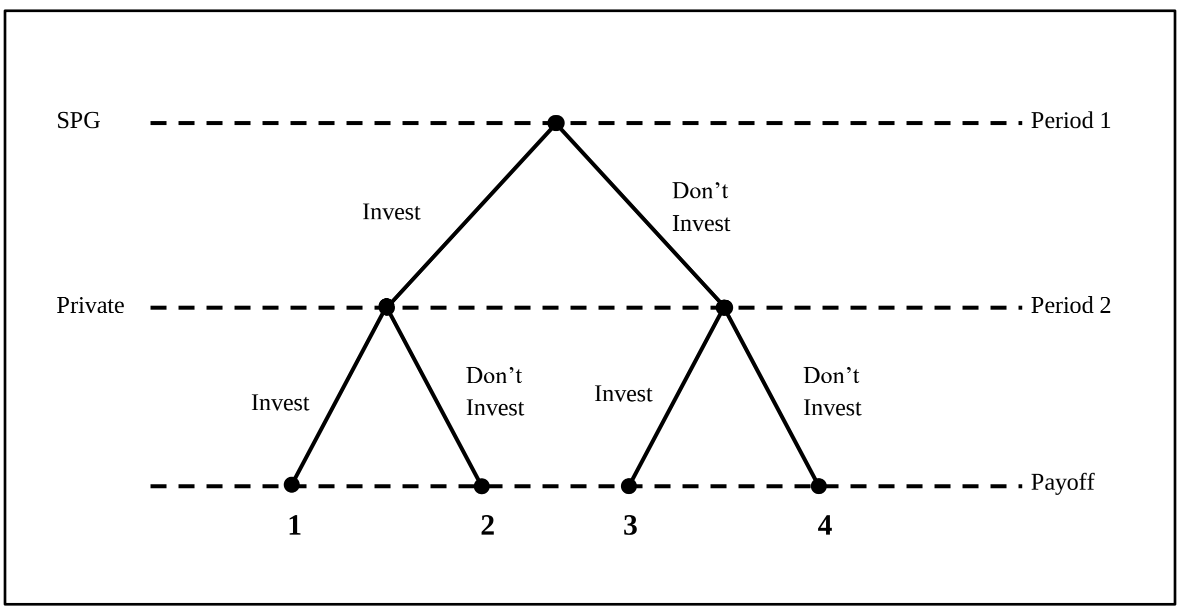
When there are fixed costs that become sunk costs, the sequence of events matter. Whereas fixed costs can be avoided if an investment is not made, once incurred at least a portion of costs become sunk costs, which cannot be recovered. In the case of a new breeding program, many fixed costs would need to be incurred, some of them transactional in nature (hiring employees, developing and supply chain) and some physical in nature (preparing land, buildings, equipment). Once incurred, many of these costs become sunk and cannot be recovered. When sunk costs are present, subsequent entry of a rival can result in negative profits for an incumbent firm. It is therefore important for these firms to anticipate the future behavior of their potential competition and to operate accordingly. This behavior can be modeled in an extensive form game.

If SPG's decision to invest is modeled in an extensive form game, the decisions become more strategic. For example, SPG could make the decision to invest in a soybean breeding program, which would be followed by a private firm's decision to invest in breeding. Similarly, a private firm could make the decision to invest prior to the decision of SPG to invest or not. As described below, a particular form of the game (i.e. particular payoffs and nodes) can lead to a “hold-up problem” where neither firm invests in an otherwise viable breeding program before getting to that particular outcome, it is useful to describe the general nature of the problem and use game theory to consider the strategic behavior of players.

First consider the case where SPG moves first and makes a decision to invest or not, and the private firm moves next to make their decision. Figure 3.1 shows a decision tree for this extensive form game, including the players, actions, nodes, and end set of nodes. Notably, SPG invests before the private firm where investment decisions may lead to four different outcomes (as illustrated in figure 3.1). These outcomes may be defined as dual entry (1), SPG entry (2), private entry (3) and no entry (4).

Given the extensive form framework in figure 3.1, each player in the game has an objective to govern their investment strategy. Generally, the objective for a private firm is to maximize profits, whereas the objective for the producer elected SPG is to maximize farmer welfare. In figure 3.1, SPG’s investment decision is governed by maximizing farmer welfare, given the anticipated reaction of the private firm and their payoffs. For example, if SPG invests, it could deter private investment, which would result in outcome 2. If SPG does not invest, and it is profitable for the private firm to invest, the result will be outcome 3. SPG would then choose to invest or not depending on whether outcome 2 produced higher or lower outcome than 3.

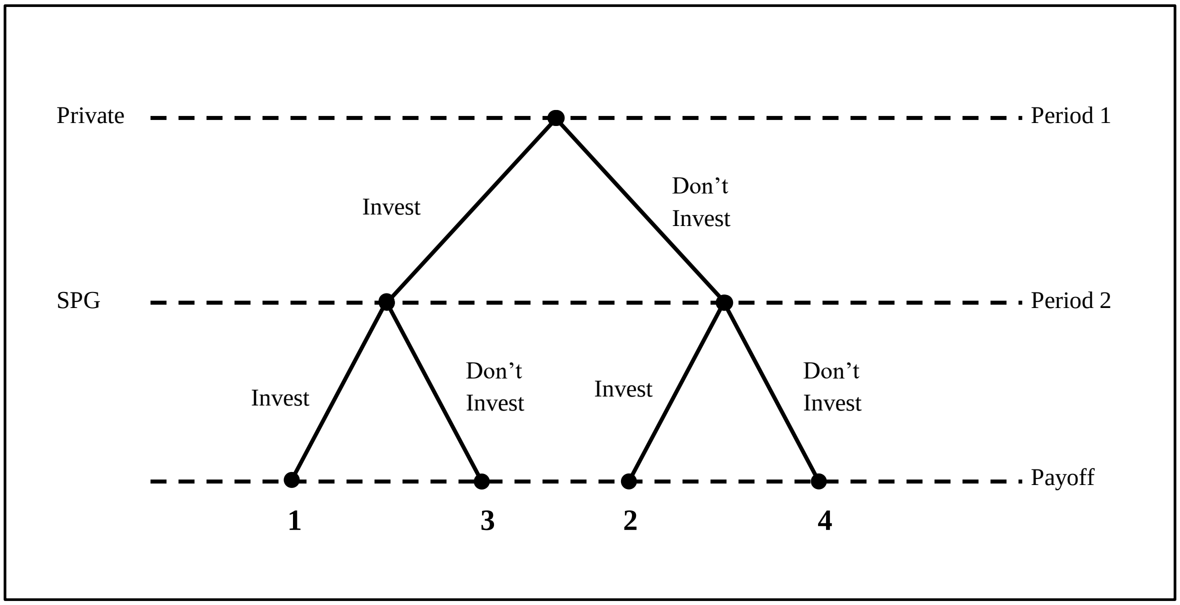
Figure 3.1: Extensive Form Game where SPG Moves First



Source: Author

Alternatively, SPG could postpone their decision to invest, and move after the private firm. This could result in a different outcome, because the two players have different incentives. If we look at figure 3.2, entry by the private firm could deter SPG investment, resulting in outcome 3. However, if SPG still finds it advantageous to enter, outcome 1 (dual entry) now becomes possible, but the private firm only invests if private profits of outcome 1 are greater than outcome 2.

Figure 3.2: Extensive Form Game where the Private Firm Moves First



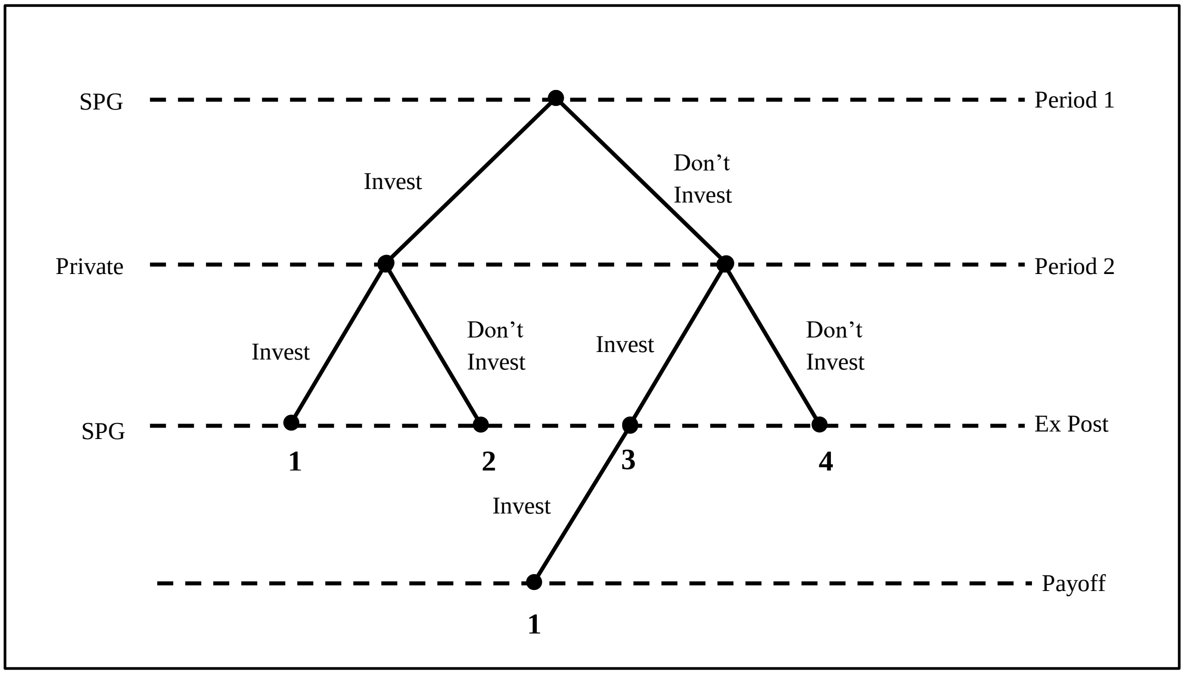
Source: Author

3.2.0 Hold-Up Problem

The hold-up problem occurs when players delay performing an action, such as signing a contract or investing in a project, in anticipation of *ex post* opportunistic behavior (Fulton, 1997). This type of hold-up problem occurs when a player's bargaining power, ex post, lowers the negotiated transfer price reducing their expected payoff. A player's bargaining power depends on the degree of asset specificity and industry structure (Williamson, 1983). The hold-up problem results in the involved player not investing at all and foregoing a profitable opportunity.

SPG has publicly indicated to assess whether entering the soybean seed market. If they are strategically waiting until a private firm incurs a large sunk cost to establish a breeding program they may be creating a hold-up problem. If entry by the private firm could deter subsequent SPG entry, then they will enter confident that SPG does not decide to follow. If on the other hand, SPG has an ex post incentive to enter after private entry, this would make private investment unprofitable resulting in outcome 1, as shown in figure 3.3. The private firm anticipating this ex pot opportunistic behavior, will not invest, creating a hold-up problem where neither SPG or the private firm enters the market.

Figure 3.3: Extensive Form Game where SPG Moves First and Ex Post



Source: Author

3.2.1 Crowding Out

In the extensive form game, if SPG invests first, the hold-up problem is no longer present. However, the probability of crowding out the private firm is a concern and a major factor in SPG's decision to enter the soybean market. Crowding out occurs when the private market's payoff is greater to not invest, after SPG has made the decision to enter. This means that the payoff for the private firm in outcome 2 is greater than the payoff in outcome 1.

To provide a clearer discussion on crowding out, a payoff matrix that includes outcomes for nodes (1) to (4) in figure 3.1 is provided in table 3.0. Table 3.0 shows the payoffs in normal form, instead of extensive form. The matrix shows payoffs for SPG and the private firm under SPG entry, private entry, dual entry, and no entry. The matrix below is not a simultaneous game; therefore, Nash equilibria are sub-game perfect and conditional on SPG's decision to invest. The private firm will choose the highest payoff given SPG's investment decision.

With the payoff matrix in Table 3.1, SPG always has an incentive to invest and will crowd out private investment in doing so, even though SPG would prefer the dual investment outcome. Importantly, the private firm will not invest in soybean breeding if SPG entry results in negative profits, when SPG has invested or when SPG has an ex post incentive to invest. This result, which seems to be consistent with current investment patterns, is of course dependent on the payoff matrix.

In reality, SPG has a number of policy instruments that they could use to increase private incentives to invest, if producers desire this outcome. SPG could, in theory, change this no investment outcome by taking measures to increase private profits in the case of dual entry. Potential measures include producing varieties that are more differentiated and less substitutable with the private varieties, by providing research spillovers to the private firm by sharing knowledge and germplasm, or by increasing their variety prices to reduce the degree of competition with the private sector.

Table 3.0. SPG and the Private Firm Payoff Matrix

Investment Payoff Matrix		***SPG***[1]	
		Do Not Invest	***Invest***
Private Firm	***Do Not Invest***	**(0, 0)**	**(1, 0)**
	Invest	**(1, 2)**	**(2, -1)**

Source: Author

[1]SPG payoffs are n, and Private Firm payoffs are m, in the (n,m) payoff for each outcome.

3.2.2 Extensive Form Game Conclusion

To summarize this discussion, we have identified that a private firm will consider the actions and impacts of potential SPG entry in soybean breeding just as SPG will consider the actions and reactions of the private firm to their breeding investments. When there are sunk costs involved, the order of investment modeled in an extensive form game can change investment outcomes. A hold-up problem can exist if SPG is waiting for private investment, has an incentive for ex post entry, and this entry would make private investment unprofitable. Ultimately, the behavior of both players will be a function of the payoff matrix as each attempt to maximize their objective, given the actions and reactions of their rivals.

The extensive form game explored in this chapter is dynamic and considers SPG and private firm investment decisions as binary. Even in this binary form, a number of outcomes are possible depending on the nature of the payoff matrix. In Chapter 4, we further explore the strategic interaction between SPG and the private firm assuming that both firms operate and choose the level of investment and pricing of their products. Both simultaneous and sequential games are employed to examine how the degree of substitutability, investment, and level of existing seed technology can impact SPG and private firm incentives for investing in soybean breeding.

Chapter 4 Two Stage Game

4.0 Introduction

This chapter now uses a two-stage game theoretical model to examine how the degree of substitutability, investment, and the level of existing seed technology impact SPG and private firm entry decisions. In contrast to chapter 3 where SPG and the private firm made the decision to invest in a soybean breeding program based on their payoffs from investing, the two-stage game assumes both firms have a program and are just considering research investment, pricing and quantity. We assume that there is a fixed cost of breeding, but no sunk costs as in chapter 3. More specifically, the game examines how the level of investment, degree of substitutability, and level of existing seed technology impact each player's investment and pricing decisions. Investment is not a binary decision in the two-stage game and each player can choose how much they invest in breeding. The two-stage game is important to the thesis as it quantifies conditions where SPG's investment in soybean breeding crowds out the private firm. This is modelled as a simultaneous investment game as well as a sequential investment game. The two-stage game shows that the degree of substitutability and existing level of seed technology have the large impact on private investment and crowding effects. These results provide important policy implications for SPG and how they decide to invest in a soybean breeding program at the CDC.

More specifically, the goal of the two-stage game is to examine how SPG investment crowds out private investment and profits. The game also examines how farmer welfare and social welfare change with SPG's breeding investment. In the first stage of the game, SPG and the private firm set their level of investment in soybean breeding. After investments have been made, SPG and the private firm select their quantity of seed to produce in the second stage. In the two-stage game, SPG's objective is to maximize farmer welfare, whereas the private firm's objective is to maximize their profits.

Because SPG has the choice to invest in a soybean breeding program at the CDC prior to the private firm's investment. The two-stage game is separated into two modelling environments that include simultaneous and sequential investments.

In the first modelling environment, SPG and the private firm invest simultaneously. The Sub-game Perfect Nash Equilibrium (SPNE) is obtained in this model where SPG and the private firm invest optimally to receive the highest payoff possible. The first modelling environment is labelled as the “Simultaneous Research game” because SPG and the private firm both invest in research simultaneously.

The second modelling environment examines whether SPG investment crowds out the private firm when investments are made sequentially. For sequential investment, SPG invests first because they are signaling the private market and showing leadership in the market. This model is a Stackelberg game meaning that the private firm invests after SPG, setting their level of investment conditional on SPG’s level of investment. SPG fully anticipates the private firm’s reaction and invests accordingly. This model also results in a SPNE for investment strategies. The second modelling environment is labelled as the “SPG Led Stackelberg game”. It differs from the Simultaneous Research game only in the first stage derivation because SPG and the private firm still set quantity simultaneously in the second stage.

The chapter outline is as follows. Section 4.1 describes the specification and initial assumption/restrictions in the two-stage game theoretical model. Section 4.2 describes the second stage of game and begins to solve the theoretical model using backward induction. The second stage of the two-stage game applies to both the Simultaneous Research game and the SPG Led Stackelberg game. Section 4.3 solves the first stage of, and conducts comparative statics for the Simultaneous Research game. The first stage of the SPG Led Stackelberg game is solved in section 4.4, and comparative statics are also developed. The chapter ends with a policy implications and conclusions section that discusses the welfare outcomes for specific investment strategies.

4.1 Model Specification

This section describes the initial specifications and assumptions that lead into solving the two-stage game. This entails deriving the inverse demand curves for SPG and private firm soybean seed. The inverse demand curves for soybean seed are derived from a quadratic production function as in Hervouet and Trommetter (2017). The inverse demand curves take a unique functional form in which the degree of sustainability is parameterized, which proportionally impacts the demand for seed in competing markets. Simply, this section discusses the specification of the production function, the derivation of demand curves from the farmers’ maximization problem, the cost of seed technology, and the model mechanics.

4.1.0 Production Function

To derive linear inverse demand curves for SPG and private soybean seed, we use a quadratic production function adapted from Hervouet and Trommetter (2017). Hervouet and Trommetter use a quadratic utility function, instead of a production function, which is given by Singh and Vives (1984) and Dixit (1979), to determine the impact of sharing knowledge between two firms in the plant breeding sector. They construct a similar two-stage theoretical model where competing firms share knowledge in the first stage and compete on quantity in the second stage. They use this functional form to parameterize the degree of substitutability and spillover effects. The quadratic utility function also makes welfare analysis tractable because the inverse-demand curves and cost functions are linear. Hervouet and Trommetter (2017) include two parameters that model the positive and negative externalities from spillover effects. Because these externalities create rather complex investment thresholds, the two-stage game theoretical model in this chapter does not include spillover effects and only the degree of substitutability.

The theoretical model developed in this thesis converts the quadratic utility function used in Hervouet and Trommetter (2017) to a production function for soybeans. This assumes that production inputs are seed where the type of seed used determines a farmer's production output. This is an appropriate assumption because output does depend on the type of seed farmers use. This functional form is preferred to the constant elasticity of substitution production function because the inverse seed demand curves derived are linear. The functional form also parameterizes the degree of substitutability between varieties. This makes the investment strategies unique because SPG can invest by seed trait, which changes the degree of substitutability.

Equation 4.1 shows the quadratic production function. Importantly, soybean output for farmers is given by the quantity of seed they purchase from SPG and the private firm and the export level of seed technology for each variety. The export level of seed technology for SPG and private varieties are represented by α_{SPG} and α_{PV}. This means that better seed technology for a certain variety leads to higher yield and output.

To represent the degree of substitutability between SPG and private soybean seed, a dependence coefficient, γ, is included in the production function. Importantly, $\gamma > 0$ means that varieties are substitutable, and $\gamma = 0$ means varieties are not substitutable. Hervouet and Trommetter (2017) state if $\gamma = \beta_{SPG} = \beta_{PV}$ then varieties are perfect substitutes and if $\gamma < 0$

varieties are complementary. In equation 4.1, there is a constraint on γ so that $\gamma \in [0,1]$ and elasticity parameters β_{SPG} and β_{PV} are normalized to unity. This means that when $\gamma = 1$, soybean varieties are perfect substitutes. If soybean varieties serve different end-use markets or vary largely in traits, then $\gamma = 0$. This means the benefit of seeding another variety when they have non-substitutable traits is zero. A farmer that seeds only biotech soybeans does not benefit from seeding food edible soybeans, and vice-versa. This is a restrictive assumption that is imposed in the production function to model the level of competition in the two-stage game.

(4.1) $$Y(q_{SPG}, q_{PV}) = \alpha_{SPG} q_{SPG} + \alpha_{PV} q_{PV} - \frac{1}{2}(\beta_{SPG} q_{SPG}^2 + 2\gamma q_{SPG} q_{PV} + \beta_{PV} q_{PV}^2)$$

Where: q_{SPG} = the quantity of SPG soybean seed
q_{PV} = the quantity of private firm soybean seed
α_{SPG} = SPG's export level of seed technology
α_{PV} = the private firm's export level of seed technology
β_{SPG} = elasticity parameter for SPG soybean seed
β_{PV} = elasticity parameter for private firm soybean seed
γ = dependence coefficient

In equation 4.2, farmers maximize their profits subject to the quantity of SPG and private firm soybean seed. Importantly, the output price, p_o, is normalized to one. Substituting the production function into this problem results in equation 4.3. From this maximization problem, the inverse demand curves for SPG and private firm soybean seed are derived. In equation 4.4, quantity has the biggest impact competitor's price when varieties are perfect substitutes. SPG and private demands may also be derived as own and competitor price (Singh and Vives, 1984; Hervouet and Trommetter, 2017).

In equation 4.4, a higher export level of seed technology (α_{SPG}, α_{PV}) increases farmers' willingness to pay for seed (Hervouet and Trommetter, 2017). In the two-stage game, SPG and the private firm can set their export level of seed technology by investing in soybean breeding. This means that α_{SPG} and α_{PV} in the two-stage game are taken as the level of investment in soybean breeding for each player. However, α_{SPG} and α_{PV} represent the investment cost of achieving a specific export level of seed technology. It is assumed that SPG and the private firm have zero marginal seed production costs. This means that the unit cost on seed is normalized to zero. SPG and the private firm are assumed to have the same unit cost for seed because they must comply with regulations on plant variety creation (Hervouet and Trommetter, 2017). SPG and the private firm both endure a fixed cost for the export level of seed technology when they invest in soybean breeding.

(4.2) $$\max_{q_{PV},q_{SPG}} \pi = p_o Y(q_{SPG}, q_{PV}) - p_{SPG}q_{SPG} - p_{PV}q_{PV}$$

(4.3) $$\max_{q_{PV},q_{SPG}} \pi = \alpha_{SPG}q_{SPG} + \alpha_{PV}q_{PV} - \frac{1}{2}(q_{SPG}^2 + 2\gamma q_{SPG}q_{PV} + q_{PV}^2) - p_{SPG}q_{SPG} - p_{PV}q_{PV}$$

(4.4) $$p_{SPG} = \alpha_{SPG} - q_{SPG} - \gamma q_{PV} \quad \text{and} \quad p_{PV} = \alpha_{PV} - q_{PV} - \gamma q_{SPG}$$

4.1.1 Cost of Seed Technology

The fixed cost of investment for SPG and the private firm is defined in equation 4.5. The cost of export seed technology for SPG and the private firm depends on the level of existing seed technology (α_i^o). If the level of existing seed technology is high, then SPG and the private firm must invest more to raise the export level of seed technology. Therefore, the difference between α_i and α_i^o represents the change in export seed technology as a result of investment in soybean breeding.

Hervouet and Trommetter (2017) constrain $\alpha_i > 0$, implying that each firm must invest a positive amount in their theoretical model. In the two-stage game, the non-negative constraint, $\alpha_i \geq \alpha_i^o$, prevents each player from investing in an export seed technology that is lower than the existing level of seed technology. This is an appropriate assumption because breeders must develop seed technology that is greater or equal to existing seed technology for variety registration in Canada. In equation 4.5, the cost function is scaled by θ to satisfy concavity in the objective functions. If θ is greater than 2.5, concavity holds in the two-stage game. However, θ is instead set to four, which is well above the threshold. This means that SPG and the private firm cannot invest an infinite amount in soybean breeding because technology costs are assumed to be expensive.

(4.5) $$C = \theta(\alpha_i - \alpha_i^o)^2 \qquad s.t. \quad \alpha_i \geq \alpha_i^o \qquad where \quad i \in \{SPG, PV\}$$

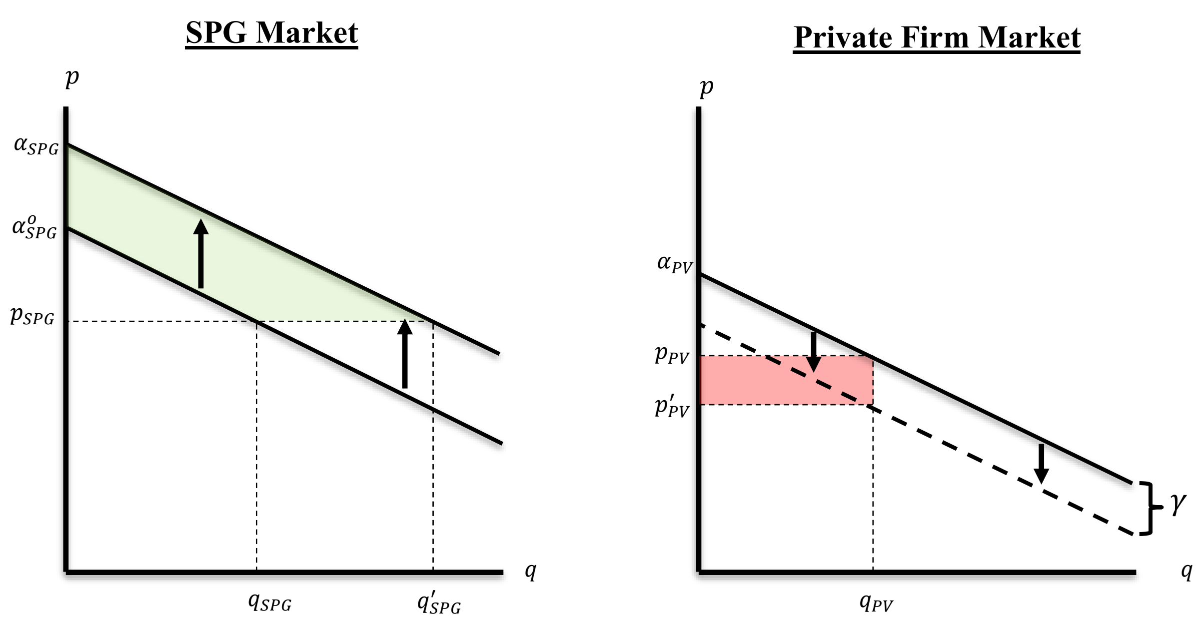
Where: α_i = the export level of seed technology
α_i^o = represents the level of existing seed technology
θ = scalar parameter

4.1.2 Model Mechanics

This section provides a simple graphical example to explain how the degree of substitutability and SPG investment impact the private firm in the two-stage game. Figure 4.0 shows the impact on the private firm from SPG investing in soybean breeding. Depending on the degree of substitutability, SPG investment shifts the demand for private seed downwards, reducing private investment, price, and profits. In the SPG seed market, investment shifts the demand for seed upwards, increasing farmer welfare in the SPG market.

In figure 4.0, the downward shift in demand for seed in the private firm market depends on the degree of substitutability between SPG and private soybeans. If SPG invests in biotech traits, resulting in varieties being close substitutes ($\gamma = 1$), the private firm could potentially be crowded out of the soybean market. If SPG invests in food edible traits, where varieties are not substitutes ($\gamma = 0$), there is less of an impact on the private firm. This assumption assumes that farmers who have access to closed loop marketing agreements for food edible soybeans have little benefit in seeding biotech soybeans. Whereas farmers that only have biotech market access from grain handlers have little benefit in seeding food edible soybeans.

Figure 4.0: Two-stage game – Impact of SPG investment on farmer welfare and private profits



Source: Author

4.2 Solving the Second Stage of the Two-Stage Game

This section presents the objective functions for SPG and the private firm and begins solving the two-stage game. The two-stage game is solved by backward induction starting in the second stage of the game. Importantly, the second stage of the game applies to both the Simultaneous Research game and the SPG Led Stackelberg game.

The objective functions for SPG and the private firm are shown in equations 4.6 and 4.7. The inverse demand curves derived from the quadratic production function are substituted into each objective function. In equation 4.6, the private firm maximizes profits with respect to the quantity of seed produced. In equation 4.7, SPG maximizes farmer welfare with respect to quantity of seed produced. SPG maximizes aggregate farmer welfare, or profit, which includes the welfare in both the SPG market and private firm market. SPG profit is not subtracted in the SPG market because profits are re-directed to farmers through investment in research.

In the cost function for seed technology (equation 4.5), SPG and the private firm had separate levels of existing seed technology. In equation 4.7, SPG's level existing of seed technology equals the private firm's level of existing seed technology (α_{PV}^{o}) multiplied by the proportional difference in the level of existing seed technology (κ). The proportional difference in the level of existing seed technology (κ) represents whether SPG's level of existing seed technology relative to the private firm's technology. When $\kappa = 0$, SPG enters the market with uncompetitive existing seed technology, whereas the private firm always has a positive level of existing seed technology ($\alpha_{PV}^{o} > 0$). The private firm has existing seed technology because they already have biotech seed in western Canada. When $\kappa = 1$, SPG has equal soybean seed technology and is fully competitive with existing private seed technology. In the two-stage game, SPG and the private firm must invest more than their level of existing seed technology where $\alpha_{SPG} - \kappa\alpha_{PV}^{o} \geq 0$ and $\alpha_{PV} - \alpha_{PV}^{o} \geq 0$. If SPG has uncompetitive existing seed technology, then investment must be greater than zero.

(4.6) $$\max_{q_{PV}} \pi_{PV} = (\alpha_{PV} - q_{PV} - \gamma q_{SPG})q_{PV} - 4(\alpha_{PV} - \alpha_{PV}^{o})^2$$

(4.7) $$\max_{q_{SPG}} FW = \int(\alpha_{SPG} - q_{SPG} - \gamma q_{PV})dq_{SPG} + \int(\alpha_{PV} - q_{PV} - \gamma q_{SPG})dq_{PV} - p_{PV}q_{PV} - 4(\alpha_{SPG} - \kappa\alpha_{PV}^{o})^2$$

Where: κ = the level of SPG existing seed technology relative to the level of private firm's existing seed technology

Equation 4.8 shows the reaction functions for SPG and the private firm, which are derived from their objective functions. The reaction functions estimate the optimal quantity that maximizes private profits or farmer welfare with respect to their competitor's quantity. When the degree of substitutability is zero, SPG supplies the whole market, whereas the private firm supplies half the market. Because there are no unit costs, the private firm sets quantity monopolistically and SPG sets quantity competitively. However, SPG and the private firm reduce quantity when seed varieties become more substitutable. This reduces the size of the soybean market when holding investment constant.

(4.8) $q_{PV} = \frac{\alpha_{PV} - \gamma q_{SPG}}{2}$ and $q_{SPG} = \alpha_{SPG} - \gamma q_{PV}$

To obtain the SPNE, SPG and the private firm must pick their optimal quantity based on their competitor's optimal quantity. This is done by substituting the reaction functions into each other and finding the intersection of the reaction curves. At the SPNE, SPG and the private firm are unable to gain from changing their quantity. Equation 4.10 shows the equilibrium quantities for SPG and the private firm. The equilibrium quantities depend only on investment and the degree of substitutability.

In equation 4.9, as the degree of substitutability increases, optimal private quantity decreases. If SPG invests more in biotech traits ($\gamma = 1$) than the private firm, private quantity is equal to zero. However, if the private firm invests twice as much as SPG in biotech traits, SPG quantity is equal to zero. When SPG invests in food edible traits and the private firm invests in biotech traits ($\gamma = 0$), both set their highest quantity.

(4.9) $q^*_{PV} = \frac{\alpha_{PV} - \gamma \alpha_{SPG}}{2 - \gamma^2}$ and $q^*_{SPG} = \frac{2\alpha_{SPG} - \gamma \alpha_{PV}}{2 - \gamma^2}$

Equation 4.10 shows the equilibrium prices for SPG and the private firm. These are solved by substituting the equilibrium quantities into the inverse seed demand curves. The private firm's optimal price is equal to their optimal quantity. However, SPG sets price equal to zero, which evidently maximizes farmer welfare.

(4.10) $p^*_{PV} = \frac{\alpha_{PV} - \gamma \alpha_{SPG}}{2 - \gamma^2}$ and $p^*_{SPG} = 0$

4.3 Solving the First Stage of the Simultaneous Research Game

This section solves the first stage of the simultaneous research game where SPG and the private firm invest in soybean breeding at the same time. To solve the first stage of the simultaneous research game, the optimal quantities and prices must be substituted into the objective functions. This means that SPG and the private firm now maximize their objective function with respect to investment at their optimal quantity and price.

In equation 4.11, the private firm maximizes profits with respect to their level of investment. Whereas SPG maximizes farmer welfare with respect to their level of investment in equation 4.12. Note that in the second stage, SPG and the private firm set quantity at a zero unit cost. In the first stage, there is a fixed cost of investment that constrains how much SPG and the private firm can invest in soybean breeding.

(4.11) $$\max_{\alpha_{PV}} \pi_{PV} = \frac{(\alpha_{PV}-\gamma\alpha_{SPG})^2}{(2-\gamma^2)^2} - 4(\alpha_{PV} - \alpha_{PV}^{o})^2$$

(4.12) $$\max_{\alpha_{SPG}} FW = \int_0^{q_i^*}(\alpha_{SPG} - q_{SPG} - \gamma q_{PV})dq_{SPG} + \int_0^{q_i^*}(\alpha_{PV} - q_{PV} - \gamma q_{SPG})dq_{PV} - p_{PV}^* q_{PV}^* - 4(\alpha_{SPG} - \kappa\alpha_{PV}^{o})^2$$

The first order conditions from the objective functions are shown in equations 4.13 and 4.14. Equation 4.14 takes a complex form due to the integration over inverse seed demand curves. Provided that farmer welfare function was defined as half base times height at the optimal quantity and price, SPG's first order condition would take a less complex form.

(4.13) $$\frac{2(\alpha_{PV}-\gamma\alpha_{SPG})}{(2-\gamma^2)^2} - 8(\alpha_{PV} - \alpha_{PV}^{o}) = 0$$

(4.14) $$\frac{4\alpha_{SPG}-\gamma\alpha_{PV}}{2-\gamma^2} - \frac{4(2\alpha_{SPG}-\gamma\alpha_{PV})}{2(2-\gamma^2)^2} - \left[\frac{-\gamma^2}{2-\gamma^2}\cdot\frac{2\alpha_{SPG}-\gamma\alpha_{PV}}{2-\gamma^2} + \frac{2\gamma}{2-\gamma^2}\cdot\frac{\alpha_{SPG}-\gamma\alpha_{PV}}{2-\gamma^2}\right] + \frac{\gamma\alpha_{PV}}{2-\gamma^2} + \frac{2\gamma(\alpha_{PV}-\gamma\alpha_{SPG})}{(2-\gamma^2)^2} - \left[\frac{2\gamma}{2-\gamma^2}\cdot\frac{\alpha_{SPG}-\gamma\alpha_{PV}}{2-\gamma^2} + \frac{-\gamma^2}{2-\gamma^2}\cdot\frac{2\alpha_{SPG}-\gamma\alpha_{PV}}{2-\gamma^2}\right] + \frac{2\gamma(\alpha_{PV}-\gamma\alpha_{SPG})}{(2-\gamma^2)^2} - 8(\alpha_{SPG} - \kappa\alpha_{PV}^{o}) = 0$$

The second order conditions from the objective functions in the first stage are negative, as shown in equation 4.15. This means that the private firm and SPG are reaching a maximum profit or farmer welfare when setting their level of investment and level of seed quality.

(4.15) $\frac{2}{(2-\gamma^2)^2} - 8 < 0$ and $\frac{4}{2-\gamma^2} + \frac{5\gamma^2-4}{(2-\gamma^2)^2} - 8 < 0$

The reaction functions are now in terms of investment for SPG and the private firm, as shown in equation 4.16. In SPG's reaction function, there is a threshold level of substitutability that changes the sign on private investment. If the private firm increases their level of investment, SPG's level of investment increases when they select food edible traits ($\gamma < 0.707$). However, private investment has a negative impact on SPG's investment when they select biotech traits ($\gamma > 0.707$). This is interesting because SPG invests more in food edible traits when the private firm increases their level of investment. In the private firm's reaction function, SPG investment always has a negative impact on their level of investment. In SPG's reaction function, SPG investment is highest when they have a relatively high level of existing seed technology (κ is high).

(4.16) $\alpha_{PV} = \frac{4\alpha_{PV}^{o}(2-\gamma^2)^2 - \gamma\alpha_{SPG}}{4\gamma^4 - 16\gamma^2 + 15}$ and $\alpha_{SPG} = \frac{8\kappa\alpha_{PV}^{o}(2-\gamma^2)^2 + \alpha_{PV}(\gamma - 2\gamma^3)}{8\gamma^4 - 33\gamma^2 + 28}$

The equilibrium investment functions for SPG and the private firm are shown in equations 4.17 and 4.18. SPG and the private firm receive the highest payoff possible when they invest where their investment reaction curves intersect. This is referred to as the SPNE because neither player can gain from changing their investment strategy. At the SPNE, optimal investment depends on the proportional difference in the level of existing seed technology (κ), the degree of substitutability (γ), and the level of existing seed technology (α_{PV}^{o}).

In equation 4.17, the difference in the level of existing seed technology has a negative impact on the private firm's optimal level of investment. This means that the private firm's optimal investment is reduced when SPG has momentum in soybean breeding. In equation 4.18, the difference in the level of existing seed technology has a positive impact on SPG's optimal level of investment. This means that it is optimal for SPG to invest more in soybean breeding when they have a high level of existing seed technology because there is more area underneath the demand curve.

(4.17) $\alpha_{PV}^{*} = \frac{\alpha_{PV}^{o}\left(4(2-\gamma^2)^2(8\gamma^4 - 33\gamma^2 + 28) - 8\kappa\gamma(2-\gamma^2)^2\right)}{(8\gamma^4 - 33\gamma^2 + 28)(4\gamma^4 - 16\gamma^2 + 15)}$

(4.18) $\alpha_{SPG}^{*} = \frac{\alpha_{PV}^{o}\left(8\kappa(2-\gamma^2)^2(4\gamma^4 - 16\gamma^2 + 15) + 4(2-\gamma^2)(\gamma - 2\gamma^3)\right)}{(8\gamma^4 - 33\gamma^2 + 28)(4\gamma^4 - 16\gamma^2 + 15) + \gamma^2 - 2\gamma^4}$

Because equations 4.17 and 4.18 are complex in the degree of substitutability, the comparative statics section further examines how substitutability impacts optimal investment. The comparative statics also examines how private profits and farmer welfare change with the degree of substitutability and the difference in the level of existing seed technology.

4.3.0 Simultaneous Research Game Comparative Statics

In the Simultaneous Research game, the only parameters that are exogenous and have an impact on optimal investment at the SPNE are the degree of substitutability (γ), level of existing seed technology (α_{PV}^{o}) and the proportional difference in the level of existing seed technology (κ). Other endogenous parameters, such as quantity (q_i), price (p_i), investment (α_i), farmer welfare (FW), and private profits (π_{PV}), cannot be used in comparative statics for the Simultaneous Research game.

This section uses these exogenous parameters to examine how substitutability and existing seed technology impact optimal price, quantity, investment, private profits, and farmer welfare. Although SPG's objective is to maximize farmer welfare, they may be hesitant to invest in traits that could potentially crowd out the private firm. SPG's authority to operate is delegated from the provincial government who may have broader interest in private sector soybean development. For this reason, SPG must consider the crowding effects, even though their objective is to maximize farmer welfare. In this section, SPG can use the degree of substitutability as a policy parameter to select traits that reduce crowding effects. Crowding effects also depend on how much SPG or Ag Canada has already invested in soybean genetics and their relative level of existing seed technology (level of κ). Because the private firm only invests in biotech traits, SPG would lower the degree of substitutability by selecting food edible traits. Momentum in soybean breeding for SPG depends on their previous investments in biotech or food edible soybean genetics.

The first comparative static analysis in this section examines how the degree of substitutability impacts optimal investment for SPG and the private firm. Equation 4.19 and 4.20 show the partial derivative of optimal investment and the degree of substitutability. Whether substitutability has a negative or positive impact on optimal investment depends on the degree of substitutability and difference in the level of existing seed technology.

Equation 4.19 shows that when SPG invests in biotech traits, substitutability has a positive impact on private investment when SPG has a low level of existing seed technology

($\kappa < 0.146$). However, SPG has a negative impact on private investment when they invest in biotech traits and have greater level of existing seed technology ($\kappa > 0.146$).

$$(4.19)\ \frac{\partial \alpha_{PV}^{*}}{\partial \gamma} = \frac{8\alpha_{PV}^{o}(\gamma^2-2)\left(\kappa(96\gamma^{10}-708\gamma^8+1840\gamma^6-1731\gamma^4-214\gamma^2+840)-2\gamma(8\gamma^4-33\gamma^2+28)^2\right)}{(8\gamma^4-33\gamma^2+28)^2(4\gamma^4-16\gamma^2+15)^2} \lesseqgtr 0$$

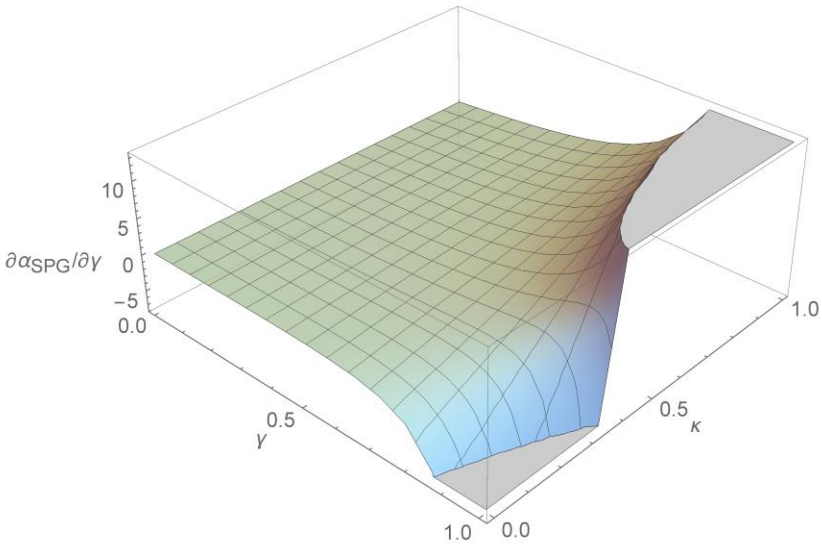
Equation 4.20 shows the effect substitutability has on SPG optimal investment. Optimal investment for SPG is negatively impacted when they invest in biotech traits and have a lower level of existing seed technology ($\kappa < 0.357$). Whereas investment is positively impacted when they invest in biotech traits with a higher level of existing seed technology ($\kappa > 0.357$). This means that it is optimal for SPG to invest more in soybean breeding when they select biotech traits and have competitive seed technology.

$$(4.20)\ \frac{\partial \alpha_{SPG}^{*}}{\partial \gamma} = -\frac{2\alpha_{PV}^{o}\left(4\kappa\gamma(8\gamma^8+40\gamma^6-396\gamma^4+840\gamma^2-555)+3(32\gamma^8-92\gamma^6-24\gamma^4+149\gamma^2-35)\right)}{(-16\gamma^6+98\gamma^4-183\gamma^2+105)^2} \gtreqless 0$$

To provide a better understanding of these relationships, three-dimensional graphs show how optimal investment for SPG and the private firm change with the level of κ and γ (figure 4.1 and 4.2). Figure 4.1 shows that the degree of substitutability positively impacts SPG's optimal investment when they have a relatively competitive level of existing seed technology. However, when SPG has no relative level of existing seed technology, they reduce their optimal investment. When varieties are not substitutable ($\gamma = 0$), regardless of the level of κ, optimal investment is unchanged. These comparative static results show that as the degree of substitutability increases, the impact of the difference in existing seed technology becomes more pronounced in both directions. When SPG has no existing technology, they lower their level of investment in soybean breeding. When SPG has competitive existing seed technology, they invest much more in breeding.

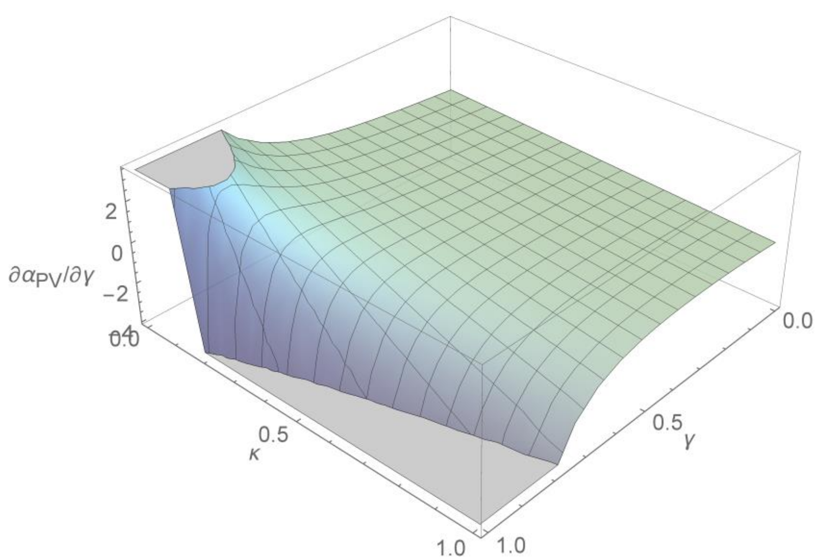
Figure 4.2 shows the opposite effect for optimal private investment. Also, the axes for γ and κ have been reversed in figure 4.2. When SPG invests in biotech traits and has competitive technology (κ is high), optimal private investment is reduced. And when SPG invests with uncompetitive existing seed technology (κ is low), optimal private investment increases. This is an important relationship in the model because SPG may not want to crowd out the private firm. Private investment is lower when SPG invests in biotech traits that are competitive with private varieties. However, the private firm invests more when SPG invests in biotech traits that are inferior to private varieties. These comparative statics shows that when substitutability is high, the marginal effects of an increase in substitutability on private investment, both positive and negative, become more pronounced. When there is high substitutability, the marginal impact switches from positive to negative for different relative SPG seed technology.

Figure 4.1: The impact of substitutability (γ) on optimal SPG investment by the degree of substitutability ($\partial\alpha^*_{PV}/\partial\gamma$) and the difference in the level of existing seed technology (κ)



Source: Author

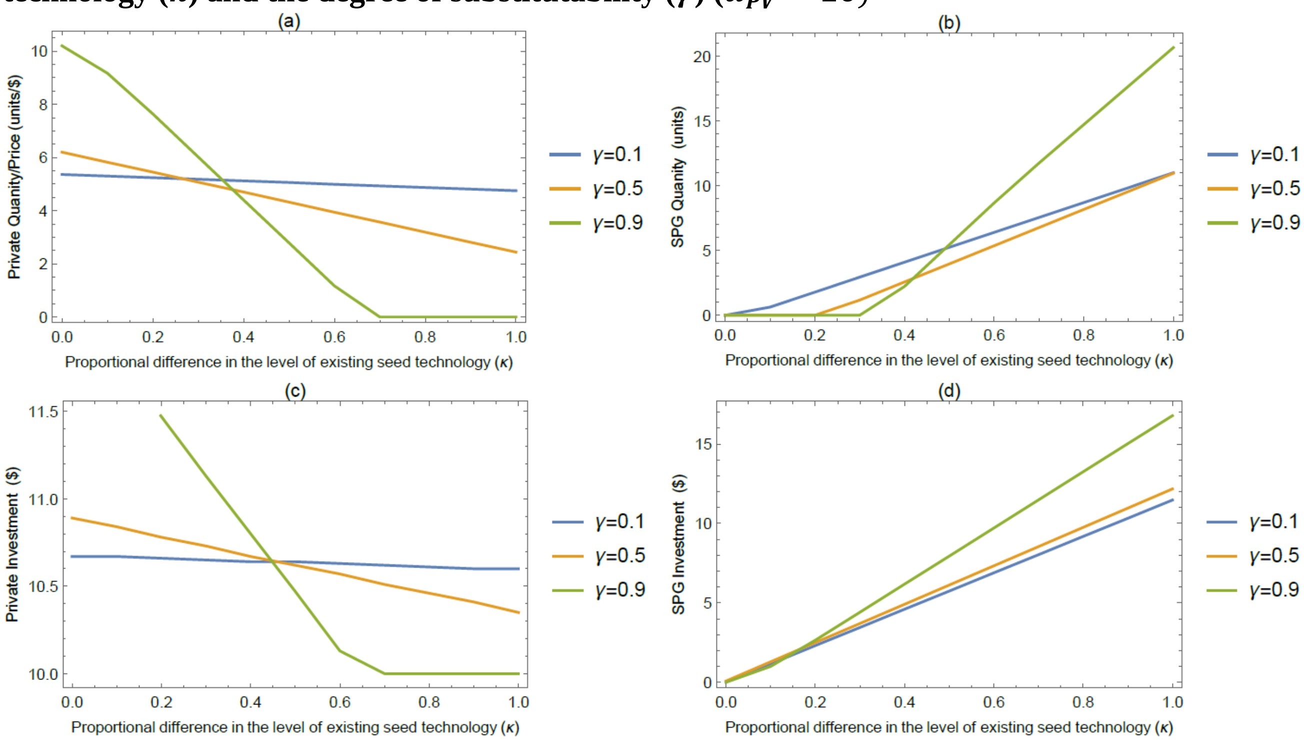
Figure 4.2: The impact of substitutability (γ) on optimal private investment by the degree of substitutability ($\partial\alpha^*_{PV}/\partial\gamma$) and the proportional difference in the level of existing seed technology (κ)



Source: Author

Figure 4.3 shows the effect of the proportional difference in the level of existing seed technology directly on private price, quantity, investment, and SPG quantity and investment. Panels (a) and (c) shows that private optimal quantity, price, and investment are reduced when SPG has a competitive level of existing seed technology. Panels (b) and (d) show that SPG optimal quantity and investment increase when they have competitive seed technology. When SPG has uncompetitive existing seed technology, SPG optimal quantity and investment reduce and private price, quantity, and investment increase.

Figure 4.3: Simultaneous Research game private and SPG optimal price, quantity, and investment with respect to the proportional difference in the level of existing seed technology (κ) and the degree of substitutability (γ) ($\alpha_{PV}^{o} = 10$)



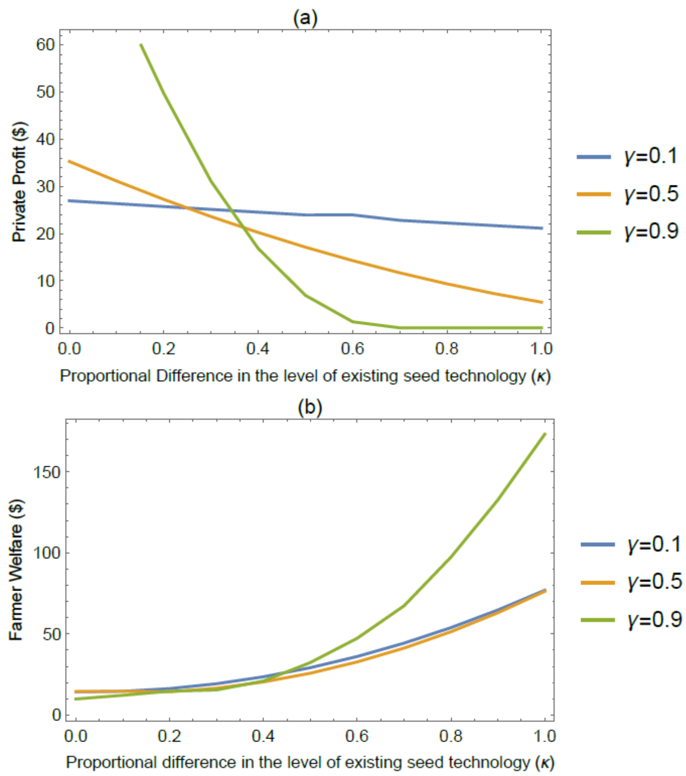
Source: Author

So far, the comparative statics indicate that when SPG has competitive existing seed technology and selects biotech traits, they reduce private price, quantity, and investment. Figure 4.4 shows that when SPG invests in biotech traits and has competitive technology, they also reduce private profits to zero. Panel (a) shows that SPG crowds out the private firm when they have a competitive level of existing seed technology and invest in biotech traits. Importantly, farmer welfare is maximized when SPG has competitive seed technology (panel (b), figure 4.4).

If SPG has uncompetitive existing seed technology, farmer welfare is reduced regardless of the degree of substitutability.

If SPG does not want to crowd out the private firm, they can either reduce substitutability by selecting food edible seed traits that do not compete with private varieties. However, SPG reduces private profits when they have competitive existing seed technology for all degrees of substitutability. The private firm is crowded out in the case where SPG invests in biotech traits and has competitive seed technology.

Figure 4.4: Simultaneous Research game private profits and farmer welfare with respect to the proportional difference in the level of existing seed technology (κ) and the degree of substitutability (γ) ($\alpha_{PV}^{o} = 10$)



Source: Author

4.3.1 Simultaneous Research Game Conclusion

The results of the Simultaneous Research game suggest that the private firm is less likely to be crowded out at lower levels of substitutability. These results are consistent with the results in Hervouet and Trommetter (2017), where spillovers have a positive impact on sharing knowledge when firms have heterogenous seed technology and one competitor has low existing seed technology. Hervouet and Trommetter (2017) results show that more competition between biotech firms results in less knowledge being shared. This is consistent in the simultaneous research game because the private firm invests less in soybean breeding when SPG selects biotech traits and has competitive existing seed technology.

To prevent crowding out, SPG may want to enter the market before the private firm. This would allow the private firm to set their investment conditional on SPG investment. Letting SPG enter the soybean market before the private firm may also prevent any holdup problems in soybean breeding. If SPG decides to invest first, the private firm's optimal investment changes because they maximize their profits conditional on SPG's level of investment. This is defined as the SPG Led Stackelberg game and is described in the next section of this chapter.

4.4 Solving the first Stage of the SPG Led Stackelberg Game

The SPG Led Stackelberg game now lets the private firm react to SPG investment in the first stage of the game. This is a sequential game because investment is now an element of time and SPG invests before the private firm. In the SPG Led Stackelberg game, SPG and the private firm still set quantity simultaneously in the second stage. Quantity cannot be modelled as Stackelberg due to concavity issues in SPG's objective function. Nevertheless, SPG has the same objective function and reaction function as seen in the Simultaneous Research game. In equation 4.21, the private firm maximizes profits subject to investment conditional on SPG investment.

$$(4.21)\quad \max_{\alpha_{PV}} \pi_{PV} = \frac{\left(\alpha_{PV} - \gamma \frac{8\kappa\alpha_{PV}^{o}(2-\gamma^2)^2 + \alpha_{PV}(\gamma - 2\gamma^3)}{8\gamma^4 - 33\gamma^2 + 28}\right)^2}{(2-\gamma^2)^2} - 4(\alpha_{PV} - \alpha_{PV}^{o})^2$$

Equation 4.22 shows the first order condition from the private firm's profit maximization problem. Equation 4.23 shows that the second order condition is negative for all degrees of substitutability. This means that the objective function results in a maximum.

$$(4.22)\quad -\frac{8\left(\alpha_{PV}^{o}\left(4\kappa\gamma(5\gamma^4 - 17\gamma^2 + 14) - (8\gamma^4 - 33\gamma^2 + 28)^2\right) + \alpha_{PV}\left(64\gamma^8 - 528\gamma^6 + 1512\gamma^4 - 1778\gamma^2 + 735\right)\right)}{(8\gamma^4 - 33\gamma^2 + 28)^2} = 0$$

$$(4.23)\quad \frac{8(7-5\gamma^2)^2}{(8\gamma^4 - 33\gamma^2 + 28)^2} - 8 < 0$$

The SPG Led Stackelberg equilibrium investment function for the private firm is shown in equation 4.24. In a Stackelberg game, the reaction function only exists for the firm first to act.

Because the private firm maximizes profits conditional on SPG investment, the SPNE for private investment is readily solved.

In equation 4.24, the difference in the level of existing seed technology has a negative impact on optimal private investment. If SPG and private soybeans are not substitutes, the difference in the level of existing technology has trivial impact on optimal private investment. This means that the degree of substitutability increases the impact SPG investment has on private investment.

$$(4.24) \quad \alpha_{PV}^{*} = \frac{\alpha_{PV}^{o}\left(\left(8\gamma^4-33\gamma^2+28\right)^2-4\kappa\gamma\left(5\gamma^4-17\gamma^2+14\right)\right)}{64\gamma^8-528\gamma^6+1512\gamma^4-1778\gamma^2+735}$$

SPG's equilibrium investment function is solved by substituting the private firm's equilibrium investment function into SPG's reaction function. This results in the SPNE for SPG optimal investment. Equation 4.25 shows equilibrium investment function for SPG. In the SPG Led Stackelberg game, a better level of existing seed technology for SPG always has a positive impact on SPG investment. This means that SPG invests more when they have competitive seed technology. The change in SPG investment remains to be greater for food-edible traits when they have uncompetitive existing seed technology, in comparison to biotech traits where the change is negative. These are the same results as shown in the three-dimensional graphs in the Simultaneous Research game.

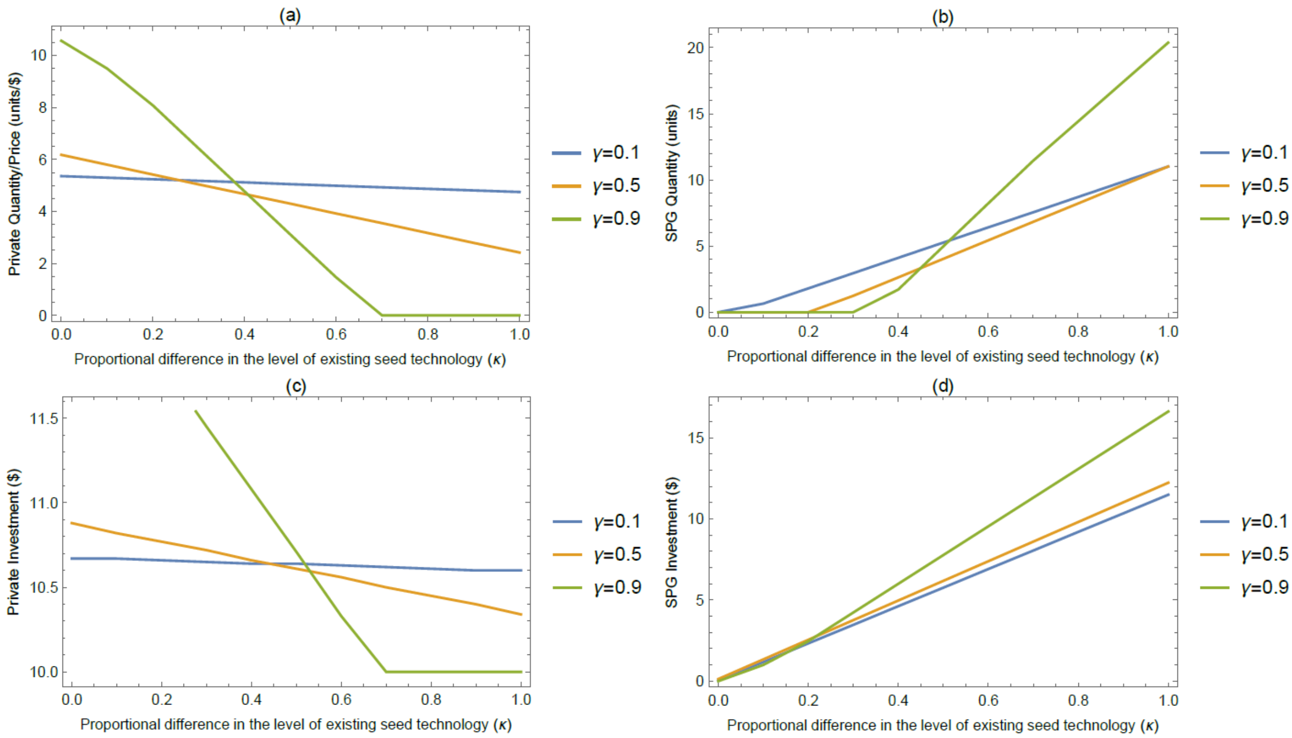
$$(4.25) \quad \alpha_{SPG}^{*} = \frac{\alpha_{PV}^{o}\left(4\kappa\left(16\gamma^8-130\gamma^6+379\gamma^4-471\gamma^2+210\right)-\left(16\gamma^7-74\gamma^5+89\gamma^3-28\gamma\right)\right)}{64\gamma^8-528\gamma^6+1512\gamma^4-1778\gamma^2+735}$$

4.3.0 SPG Led Stackelberg Comparative Statics

The comparative statics in the SPG Led Stackelberg game examines how the difference in the level of existing seed technology (κ) and the degree of substitutability (γ) impact private investment, SPG investment, private profits and farmer welfare for when SPG is the first to enter the soybean market. Again, SPG may want to enter the soybean market before the private firm to prevent a holdup problem.

Figure 4.5 shows the optimal price, quantity and investment for SPG and the private firm by the proportional difference in the level of existing seed technology under different degrees of substitutability. The results in the SPG Led Stackelberg game are identical to the Simultaneous Research game where private price, quantity, and investment reduces when SPG has competitive technology and selects biotech traits. This suggests that SPG reduces private price, quantity, and investment even when they enter the soybean market before the private firm.

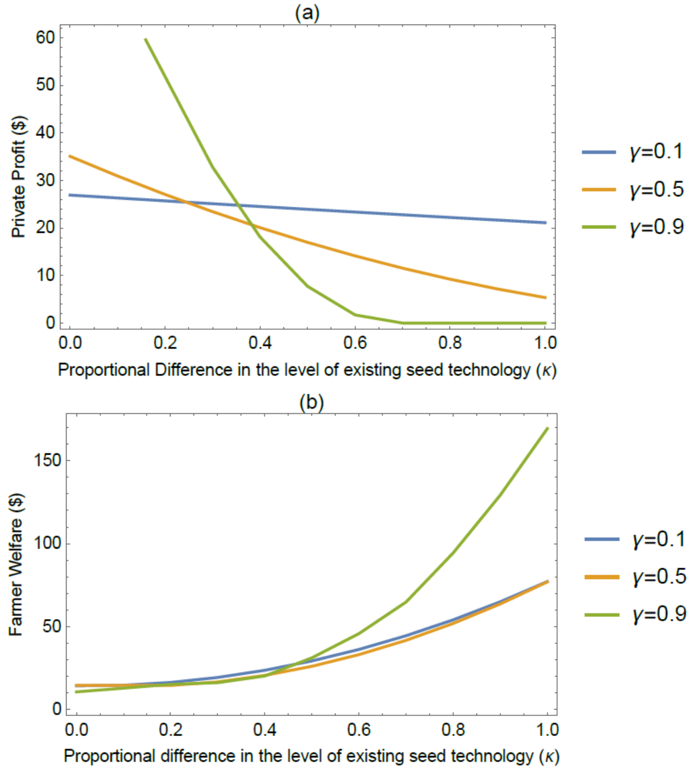
Figure 4.5: SPG Led Stackelberg game private and SPG optimal price, quantity, and investment with respect to the proportional difference in the level of existing seed technology (κ) and the degree of substitutability (γ) ($\alpha_{PV}^{o} = 10$)



Source: Author

Figure 4.6 shows the impact of the difference in the level of existing seed technology on private profits and farmer welfare in the SPG Led Stackelberg game. If SPG enters the market first, the private firm does not enter when SPG selects biotech traits and competitive seed technology (panel (a), figure 4.6). However, private profits are greater when SPG has uncompetitive existing seed technology and invests in biotech traits (panel (a), figure 4.5). If SPG has competitive technology and invests in food-edible traits, the private firm enters the soybean market and is not crowded out. For all degrees of substitutability, farmer welfare is greatest when SPG has a competitive level of existing seed technology (panel (b), figure 4.5). The SPG Led Stackelberg game results are all consistent with the Simultaneous Research game.

Figure 4.6: SPG Led Stackelberg game private profits and farmer welfare with respect to the proportional difference in the level of existing seed technology (κ) and the degree of substitutability (γ) ($\alpha_{PV}^{o} = 10$)



Source: Author

4.3.2 SPG Led Stackelberg Game Conclusion

The results of the SPG Led Stackelberg game suggest that SPG's decision to invest before the private firm provides similar results on crowding effects and welfare as seen in the Simultaneous Research game. This makes sense because if SPG enters with traits that crowd out the private firm as seen in the Simultaneous Research game, the private firm is still crowded out regardless of whether they choose to invest first or simultaneously. The comparison of results between the Simultaneous Research game and SPG Led Stackelberg game are discussed in the policy implications and conclusions section in more detail.

4.4 Policy Implications and Conclusions

In western Canada, investment in soybean breeding is becoming more important as soybean adoption increases. The two-stage game shows that farmer welfare is greatest when SPG invests in biotech traits and has competitive seed technology (column 4, table 4.0). However, this crowds out the private firm reducing their profits to zero. If SPG invests in food edible traits, farmer welfare and social welfare are relatively high when SPG has competitive seed technology (column 3, table 4.0). The private firm's profits are greatest and farmer welfare is the lowest if SPG invests in biotech traits with uncompetitive seed technology (column 2, table 4.0). Private profits are positive when SPG has uncompetitive technology and invests in food edible traits, but social welfare is the lowest in this case (column 1, table 4.0).

Table 4.0: Strategic Investment Strategy Outcomes

Parameter/Estimate	Game	[1] Food edible/ Uncompetitive Technology $\gamma_{=0.1}; \kappa_{=0.1}$	[2] Biotech/ Uncompetitive Technology $\gamma_{=0.9}; \kappa_{=0.1}$	[3] Food edible/ Competitive Technology $\gamma_{=0.1}; \kappa_{=0.9}$	[4] Biotech/ Competitive Technology $\gamma_{=0.9}; \kappa_{=0.9}$
Private Price/Quantity	Simultaneous Research game	5.30	9.17	4.81	0
	SPG Led Stackelberg game	5.30	9.50	4.81	0
SPG Quantity	Simultaneous Research game	0.63	0	9.84	17.67
	SPG Led Stackelberg game	0.65	0	9.86	17.40
Private Investment	Simultaneous Research game	10.67	11.80	10.60	10.00
	SPG Led Stackelberg game	10.67	12.20	10.60	10.00
SPG Investment	Simultaneous Research game	1.16	1.00	10.32	15.02
	SPG Led Stackelberg game	1.18	1.00	10.34	14.85
Private Profits	Simultaneous Research game	26.33	70.95	21.68	0.00
	SPG Led Stackelberg game	26.32	70.80	21.67	0.00
Farmer Welfare	Simultaneous Research game	14.59	12.11	64.73	132.68
	SPG Led Stackelberg game	14.61	12.84	64.92	129.21
Social Welfare	Simultaneous Research game	40.92	83.06	86.41	132.68
	SPG Led Stackelberg game	40.92	83.65	86.59	129.21

Source: Author's Estimates

SPG's main objective is to maximize farmer welfare, regardless of whether they crowd out the private firm. In this case, they should invest in biotech soybeans when they have competitive seed technology. However, SPG can reduce crowding effects, if required by government regulation, by reducing their level of investment and/or lowering their level of existing seed technology. This is shown in columns 2 of table 4.0 where private profits increase in which SPG lowers their level of existing seed technology. However, SPG does not produce any quantity in this case and gives up breeding, handing over the soybean market to the private firm. In column 3 of table 4.0, private profits increase by SPG lowering their degree of substitutability with private varieties. In this case, SPG still produces a positive quantity of seed without crowding out the private firm. These results apply to both games and does not matter whether SPG is the first to invest in soybean breeding or simultaneously with the private firm.

If SPG is restricted by government to select a strategy that does not crowd out the private firm, they should invest in food edible traits. This investment strategy is likely to have spillover effects from SPG developing better soybean germplasm and increasing the level of existing seed technology. This statement is supported by Hervouet and Trommetter (2017) where heterogeneity in products remain to have positive spillover effects, but, reduce the negative externalities from competition when sharing knowledge.

Because the two-stage game is a simple stylized model, the next chapter develops a simulation to quantify the benefit to farmers from SPG investing in soybean breeding in western Canada. The simulation is an empirical model, as opposed to a theoretical model, that uses data on acres, yield, investment, prices, and costs to simulate the growth in acres and yield over twenty years, under a number of specific pricing and investment choices.

Chapter 5 Simulation

5.0 Introduction

As noted in Chapter 1, with the increase in soybean acres in Saskatchewan, SPG must make some important investment decision based on their interests and goals in soybean breeding. As described in chapter 3, if SPG decides not to invest in breeding, the hold-up problem and lack of private investment reduces welfare for farmers in western Canada. In chapter 4, the game theoretic models explore how optimal investment would change depending on SPG's investment strategy. We found that while these results provide important insights as to how SPG and the private sector may interact in the market place, SPG is faced with an important and difficult decision of whether to invest millions of dollars of levy income in breeding producer owned soybean varieties. The leadership and growers they represent need to understand more than just the theoretical effects of such a move. They need to be able to anticipate and quantify foreseeable outcomes from alternative investment strategies.

The purpose of the simulation, which is described in this chapter, is to quantify how alternate hypothetical investments in soybean breeding impact private profits, farmer welfare, and social welfare.

This will involve quantifying the likely impact of investment on yields, soybean seed prices, and in turn the impacts on gross margins, market shares and the overall growth of the soybean industry. To reduce the myriad of possible investment and pricing strategies, we consider three fixed investment rates, three levels of substitutability, three pricing levels, two research spillover environments, and two equity funded environments. In contrast to the two-stage game where firms select their investment level, we examine the impact of investment while imposing realistic constraints on how much funds SPG and the private market can allocate to a soybean breeding program. The results of these simulations have important policy implications for SPG and their decision to invest and select traits in soybean breeding.

The model simulates 20 years of investment in soybean breeding. Here SPG competes against a "private market", rather one-on-one (i.e. SPG vs. the private firm), as modelled in the extensive form game and two-stage game. The simulation uses a multi-crop producer surplus function to derive the elasticities between SPG and private soybeans, and other crops. This new functional form allows us to model the seed demand framework in ways that can be parameterized using industry and academic data.

Throughout this chapter, we quantify soybean yield, price, cost and acres for SPG using conventional soybeans and quantify private yield, price, cost, and acres with roundup ready soybeans. This is because traditionally, producer groups have used conventional breeding methods, while the private market has used biotechnology to breed seed. However, this does not imply that SPG will follow this course, and we simulate a range of options. Importantly, roundup ready is a registered trademark for the roundup ready trait (glyphosate tolerant) owned by Monsanto. Most of the private market soybean varieties contain this trait.

This chapter begins with the *Methodology* section, section 5.1, which derives the own and cross acreage elasticities from the multi-crop producer surplus function. Section 5.2, *Data Description and Base Parameters,* describes the data and base parameters section and explains the specification for yield response to investment and spillover effects. Section 5.3, *Simulation Results*, provides the results for the simulation varying by substitutability. Section 5.4, *Sensitivity Analysis*, includes a sensitivity analysis to examine how the acreage elasticity, spillover effects, price, and investment impact economic surplus. This is followed by section 5.5, the *Summary and Conclusions* section.

5.1 Methodology

5.1.0 Introduction

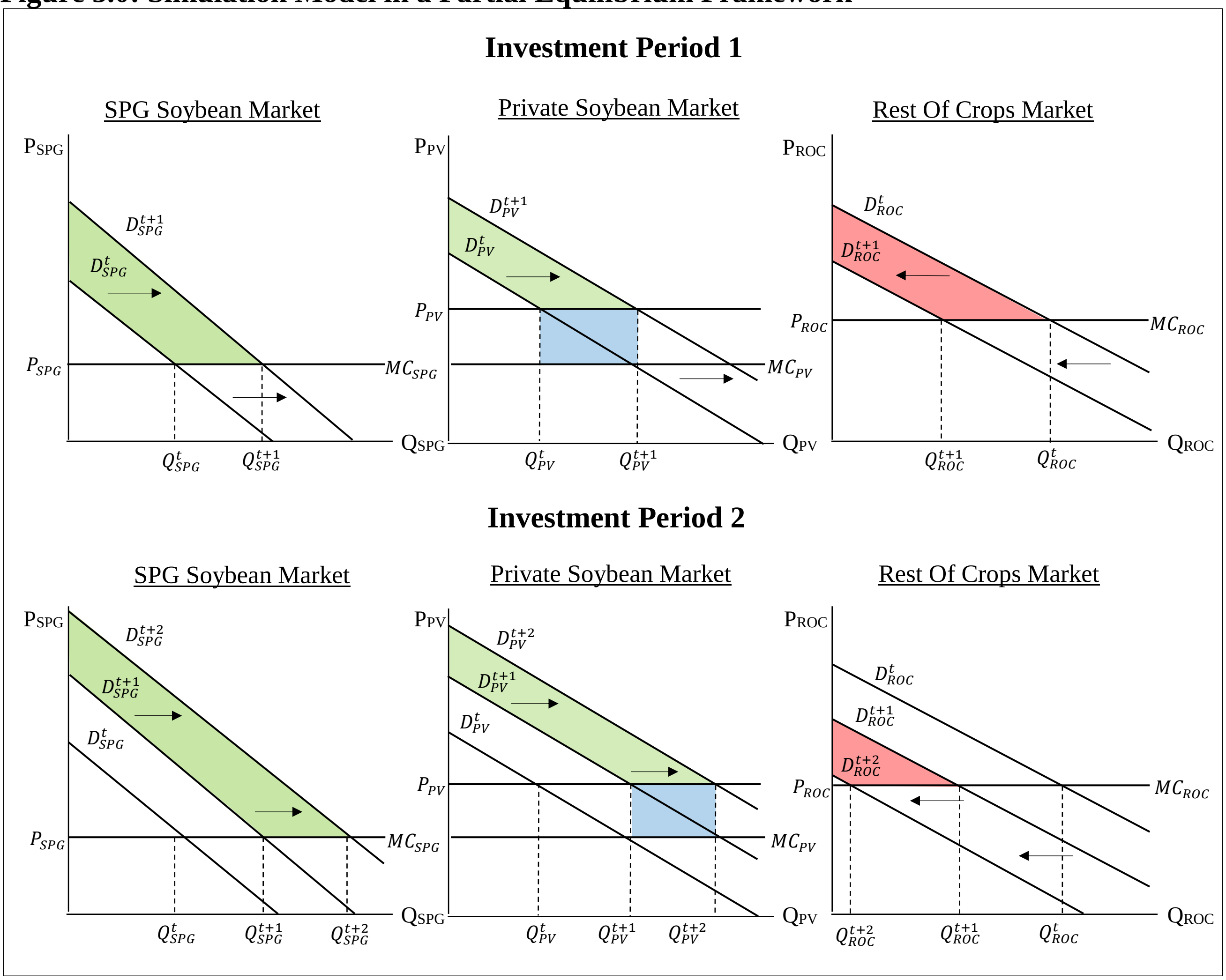
In this section, we describe the simulation model, which incorporates an acreage response function to changes in genetic yield and price, parameterized using existing empirical estimates and theoretical constraints. For each year of the simulation model, we use the acreage response function to estimate the partial equilibrium demands for SPG and private market soybeans as a function of the genetic yield index and seed price for 20 years. These market equilibria are in turn used to estimate the impact on gross margins, welfare and overall growth of the soybean industry.

Figure 5.0 illustrates how the simulation captures the economic effects of breeding investment using a partial equilibrium model. In this partial equilibrium model, breeding increases the genetic yield index and shifts the demand for soybeans outwards in each period.

In the first and second investment period, SPG and the private market both invest in soybean breeding. This increases the genetic yield index, shifting the demand for seed (D)

outwards in the next time period. When holding price (P) and marginal cost (MC) constant, investment increases the quantity of seed farmers purchase from SPG and the private market. In figure 5.0, the green shaded area represents the positive change in farmer welfare, whereas the blue shaded area represents the positive change in private profits. Because total acres are fixed, there is a reduction in the demand for seed of other crops (D_{ROC}), when the quantity of seed increases in the soybean market (Q_{SPG}; Q_{PV}). The red shaded area in this market represents the negative change in farmer welfare. Using this theoretical model as the basis for the simulation, we are able calculate the per period benefit and net present value to farmers and private companies, for various investment, pricing, and substitutability scenarios. Comparing these scenarios provides important policy implications for SPG and their decision to invest in soybean breeding.

Figure 5.0: Simulation Model in a Partial Equilibrium Framework



Source: Author

The partial equilibrium model in figure 5.0 is incorporated with a forward-looking simulation that contains additional conditions set out to quantify the change in soybean demand from investment in breeding. When defining parameters in the simulation, it is essential to ensure realistic decisions, rules, and outcomes for SPG and the private market.

As an overview of the simulation model, a simple flow chart is shown in figure 5.1. For each step in the simulation, we provide a list of conditions undertaken in performing specific calculations.

Importantly, the *Simulation Parameterization* is not a part of the simulation model. Prior to running the simulation, we first derive the own and cross acreage response gross margins elasticities and estimate the yield response to investment and spillover rate functions. To form defendable estimates of the partial equilibrium outcomes, it is critically important that we parameterize the acreage response elasticities from previous empirical studies. These studies show that the elasticities are internally consistent with symmetry and adding up conditions (Chavas and Holt, 1990). We also impose a degree of substitutability parameter on the SPG and the private market soybean acreage response gross margins elasticities. The yield response to investment and spillover rate functions are estimated using academic and industry data. Both functions estimate an annual yield growth for investment in breeding, and with the acreage response elasticities, quantify the shift in demand for soybean seed.

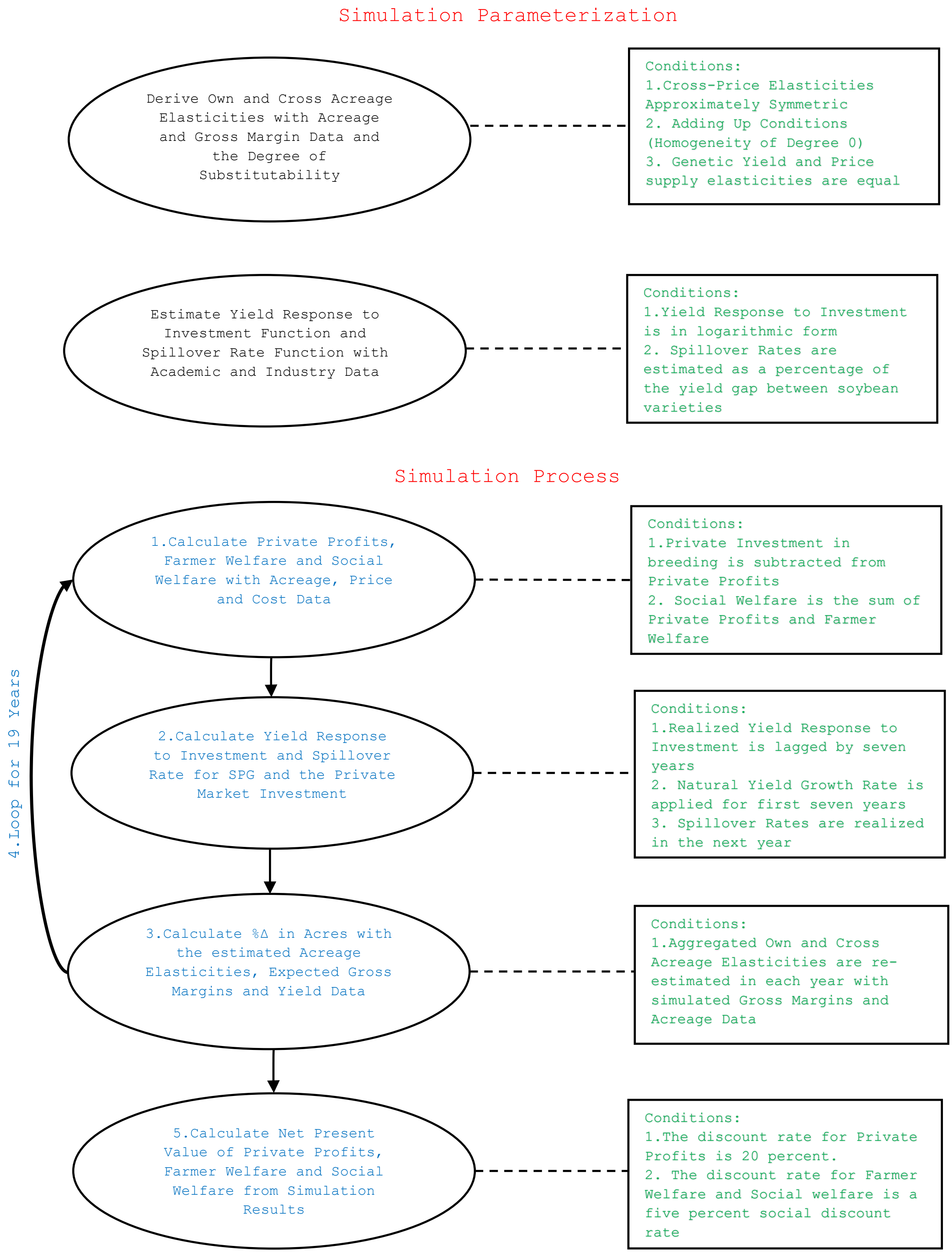
After these parameters have been quantified, we are able to define commands that are needed to run the simulation model in *Simulation Process*.

The simulation model computes the change in acres, yield, gross margins, private profits, farmer welfare, and social welfare for 20 years of investment. The simulation process involves five steps,

The first step of the simulation model is to estimate private profits, farmer welfare and social welfare in the first year. Data for acres, yield, price, and cost, provided by industry and academic sources in the 2017 crop year, are used in the first year. In the next step, we calculate SPG's and the private market's level of investment in soybean breeding, which is then used to estimate the yield response to investment and spillover rate. The genetic yield gains from investment provide farmers with an expected gross margin for improved soybean seed in the following year. The third step is to estimate the change in soybean acres in the next year using the acreage response gross margins elasticities. In the fourth step, we loop the first three steps for nineteen years and stop at year 20 in the simulation. In the fifth step, we obtain the simulated results for twenty years of investment in soybean breeding and estimate the net present value of private profits, farmer welfare, and social welfare. Once we have completed the simulation for the base case, we then simulate alternate SPG investment and pricing policies. We are able to assess the economic impacts of these policies by comparing the outcomes to the base case.

In Section 5.1, we derive the own and cross acreage response gross margins elasticities using a multi-crop producer surplus function, Hotelling's Lemma, Young's Theorem, and adding up conditions. This is followed by the Data Description and Base Parameters section, which shows the simulation data and base parameters, and estimates the yield response to investment and spillover rate functions.

Figure 5.1: Simulation Flow Chart of Estimation Procedure with Conditions



Source: Author

5.1.1 Multi-Crop Producer Surplus Constrained Maximization Problem

In the multi-crop producer surplus function, farmers' objective is to maximize their surplus subject to acres and inputs of private market roundup ready soybeans, SPG conventional soybeans, and other crops. The objective function in equation 5.1 incorporates a yield index to control for the diminishing returns by acres and inputs of a specific crop. This assumption prevents a farmer from seeding their whole farm to a crop with the highest gross margins. In this model, we assume that the realized yield decreases when farmers begin to allocate an excessive amount of acres and inputs to a particular crop. We find this to be an appropriate assumption because using too much fertilizer or seed can reduce the yield of a crop. Also, allocating too much of your farmable acres to a particular crop has a negative impact on realized yield because of the poor crop rotation and management that could further increase soil nutrient deficiencies, salinity, weed pressure, and disease risk. The notation in equation 5.1 is standard throughout the rest of this chapter. SPG soybeans are denoted by *i*, private market soybeans are denoted by *j*, and other crops are denoted by *k*.

(5.1) $\max_{A_n, x_n} PS = \sum_{n \in i,j,k} [P_n y_n - w_n x_n] A_n \quad s.t. \quad \sum_{n \in i,j,k} A_n = \bar{A}$

Where: $n \in \{i, j, k\}$

$P_n =$ output price of crop *n*

$y_n =$realized yield of crop *n*

$w_n =$input cost of crop *n*

$x_n =$level of inputs of crop *n*

$A_n =$acres of crop *n*

$\bar{A} =$total acres

Equation 5.2 defines the realized yield as being dependent on the yield index, and the proportion/level of inputs and acres of each crop. In this equation, $k(\cdot)$ is a function of the inputs and acres of all crops.

(5.2) $y_n = \hat{Y}_n \cdot k(\boldsymbol{x}, \boldsymbol{A}) \quad where \quad \boldsymbol{x} \in (x_i, x_j, x_k) \quad and \quad \boldsymbol{A} \in (A_i, A_j, A_k)$

Where:

$\hat{Y}_n =$genetic yield index of crop n

To ensure an internal solution where all crops are grown with finite yield, we assume diminishing returns with respect to the level of inputs and acres. This is shown in equation 5.3, where the function $k(\cdot)$ decreases with respect to acres and inputs.

(5.3) $\frac{\partial k(\boldsymbol{x},\boldsymbol{A})}{\partial A_n} < 0 \quad and \quad \frac{\partial k(\boldsymbol{x},\boldsymbol{A})}{\partial x_n} < 0$

In equation 5.4, we substitute the reduced form realized yield into the producer surplus maximization problem.

(5.4) $\max_{A_n, x_n} PS = \sum_{n \in i,j,k} \left[P_n \hat{Y}_n \cdot k(\boldsymbol{x},\boldsymbol{A}) - w_n x_n \right] A_n \qquad s.t. \quad \sum_{n \in i,j,k} A_n = \bar{A}$

To solve the maximization problem for acres and inputs with the land constraint, we use a LaGrange, which solves for a constrained maximization problem. This is shown in equation 5.5.

(5.5) $\max_{A_n, x_n} \mathcal{L} = \sum_{n \in i,j,k} \left[P_n \hat{Y}_n \cdot k(\boldsymbol{x},\boldsymbol{A}) - w_n x_n \right] A_n - \lambda\left(\sum_{n \in i,j,k} A_n - \bar{A}\right)$

The First Order Conditions (FOCs) from the constrained maximization problem are shown in equations 5.5 to 5.7.

FOCs:

(5.5) $\frac{\partial \mathcal{L}}{\partial A_n} = \sum_{n \in i,j,k} P_n \hat{Y}_n \cdot k'(\boldsymbol{x},\boldsymbol{A}) A_n + P_n \hat{Y}_n \cdot k(\boldsymbol{x},\boldsymbol{A}) - w_n x_n - \lambda = 0$

(5.6) $\frac{\partial \mathcal{L}}{\partial x_n} = \sum_{n \in i,j,k} P_n \hat{Y}_n \cdot k'(\boldsymbol{x},\boldsymbol{A}) A_n - w_n A_n = 0$

(5.7) $\frac{\partial \mathcal{L}}{\partial \lambda} = \sum_{n \in i,j,k} A_n - \bar{A} = 0$

By algebraic isolation, the FOCs solve for the producer surplus maximizing output supply, input demand, and acreage supply functions. In equations 5.8 to 5.10, the optimal output supply, input demand, and acreage supply all reduce and depend on the output price, yield index, input price, and total acres.

(5.8) $y_n^* = \hat{Y}_n \cdot k\left(P_n, \hat{Y}_n, w_n, \bar{A}\right)$

(5.9) $x_n^* = x_n\left(P_n, \hat{Y}_n, w_n, \bar{A}\right)$

(5.10) $A_n^* = A_n\left(P_n, \hat{Y}_n, w_n, \bar{A}\right)$

Substituting equations 5.8 to 5.10 back into the multi-crop producer surplus function solves for the indirect producer surplus function in reduced form. The indirect producer surplus function is shown in equation 5.11.

(5.11) $PS^* = PS\left(P_n, \hat{Y}_n, w_n, \bar{A}\right)$

By Hotelling's Lemma, the output supply and input demand are solved by deriving with respect to output and input price. Hotelling's Lemma applied to the indirect producer surplus function is shown in equations 5.12 and 5.13.

(5.12) $\frac{\partial PS^*}{\partial P_n} = y_n^*$

(5.13) $-\frac{\partial PS^*}{\partial w_n} = x_n^*$

In equation 5.14, defining the gross margin index for a farmer as price times the yield index makes it possible to solve for the acreage supply.

(5.14) $G_n = P_n \hat{Y}_n$

Because the gross margin index is exogenous to the firm, we can derive producer surplus maximizing acreage supply as a function of G_n, w_n and $\bar{A}$. Because of Young's Theorem, we know that price effects on y_n^* are symmetric (equation 5.15). However, the price effects on A_n^* cannot be symmetric unless the yield per acre is invariant to prices, which they are not. That being said, we make the argument that acreage response effects are approximately symmetric because yield per acre are nearly invariant to prices (equations 5.16 and 5.17). For modeling purposes, we assume that acreage response is similar to supply response, and is symmetric. The sum of acreage responses from a price or yield index change must sum to zero because land is fixed (equation 5.18).

(5.15) $\frac{\partial^2 PS^*}{\partial P_i \partial P_j} = \frac{\partial y_i^*}{\partial P_j}$ and $\frac{\partial^2 PS^*}{\partial P_j \partial P_i} = \frac{\partial y_j^*}{\partial P_i}$

(5.16) $\frac{\partial^2 PS^*}{\partial P_i \hat{Y}_i \partial P_j} \approx \frac{\partial A_i^*}{\partial P_j}$ and $\frac{\partial^2 PS^*}{\partial P_j \hat{Y}_j \partial P_i} \approx \frac{\partial A_j^*}{\partial P_i}$

(5.17) $\frac{\partial^2 PS^*}{\partial P_i \hat{Y}_i \partial \hat{Y}_j} \approx \frac{\partial A_i^*}{\partial \hat{Y}_j}$ and $\frac{\partial^2 PS^*}{\partial P_j \hat{Y}_j \partial \hat{Y}_i} \approx \frac{\partial A_j^*}{\partial \hat{Y}_i}$

(5.18) $\sum_{n \in i,j,k} \frac{\partial A_n^*}{\partial P_n} = 0$ and $\sum_{n \in i,j,k} \frac{\partial A_n^*}{\partial \hat{Y}_n} = 0$

The optimal acreage supply, as shown in equation 5.19, is approximately solved by Hotelling's Lemma, given that price is nearly invariant to the yield index.

(5.19) $\frac{\partial PS^*}{\partial G_n} = \frac{\partial PS^*}{\partial P_n \hat{Y}_n} \approx A_n^*$

Because the gross margin index is a product of price and the yield index, the price elasticity, the yield index elasticity, and the gross margin index elasticity are identical.

(5.20) $e_{\hat{Y}_n} = \frac{\partial A_n^*}{\partial \hat{Y}_n} \frac{\hat{Y}_n}{A_n} \approx e_{P_n} = \frac{\partial A_n^*}{\partial P_n} \frac{P_n}{A_n} \approx e_{G_n} = \frac{\partial A_n^*}{\partial G_n} \frac{G_n}{A_n}$

5.1.2 Gross Margin Own and Cross Acreage Elasticities

The gross margins index elasticity presented in the previous section is used to estimate the own and cross acreage elasticities with restrictions. In the simulation model, gross margins increase when the yield index increases from investment in soybean breeding. Own and cross acreage elasticities are estimated assuming homogeneity of degree zero. This assumption is enforced by the land constraint meaning that the overall change in acres must sum to zero. Homogeneity of degree zero assumes that the proportion of soybean acres relative to total acres is constant when all crop prices change proportionally. Chavas and Holt (1990) show that the homogeneity condition implies acreage decisions are determined by relative prices and costs. In equation 5.21, the homogeneity condition is defined in the acreage response matrix.

(5.21) $\begin{bmatrix} \gamma_{ii} & \gamma_{ji} & \gamma_{ki} \\ \gamma_{ij} & \gamma_{jj} & \gamma_{kj} \\ \gamma_{ik} & \gamma_{jk} & \gamma_{kk} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$

Where: $\gamma_{nn} = \frac{\partial A_n^*}{\partial G_n}$

By Young's Theorem, we can state that the acreage response to a change in the gross margin index are approximately symmetric. This is shown in equations 5.22 to 5.24.

(5.22) $\gamma_{ij} \approx \gamma_{ji}$

(5.23) $\gamma_{ik} \approx \gamma_{ki}$

(5.24) $\gamma_{jk} \approx \gamma_{kj}$

Multiplying the equation 5.22 to 5.24 by $\frac{G_n}{A_n}\frac{A_n}{G_n}$ results in the following elasticity relationships, given by symmetry, which are shown in equations 5.25 to 5.27.

(5.25) $e_{ji} = e_{ij}\frac{A_i}{A_j}\frac{G_i}{G_j}$

(5.26) $e_{ki} = e_{ik}\frac{A_i}{A_k}\frac{G_i}{G_k}$

(5.27) $e_{kj} = e_{jk}\frac{A_j}{A_k}\frac{G_j}{G_k}$

Multiplying γ_{nn} by $\frac{G_n}{A_n}\frac{A_n}{G_n}$ into the matrix in equation 5.21 results in the product of the own and cross acreage elasticities and acres divided by the gross margins index. This result is shown in equation 5.28.

(5.28) $$\begin{bmatrix} e_{ii}\frac{A_i}{G_i} & e_{ji}\frac{A_j}{G_i} & e_{ki}\frac{A_k}{G_i} \\ e_{ij}\frac{A_i}{G_j} & e_{jj}\frac{A_j}{G_j} & e_{kj}\frac{A_k}{G_j} \\ e_{ik}\frac{A_i}{G_k} & e_{jk}\frac{A_j}{G_k} & e_{kk}\frac{A_k}{G_k} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

From equation 5.28, the remaining elasticity relationships are solved by assuming homogeneity, as shown in equations 5.29 to 5.31.

(5.29) $$-e_{ji} = e_{ii}\frac{A_i}{A_j} + e_{ki}\frac{A_k}{A_j}$$

(5.30) $$-e_{ij} = e_{jj}\frac{A_j}{A_i} + e_{kj}\frac{A_k}{A_i}$$

(5.31) $$-e_{ik} = e_{kk}\frac{A_k}{A_i} + e_{jk}\frac{A_j}{A_i}$$

The simulated acreage elasticities are estimated with gross margins data, acreage data, and a proxy pea acreage elasticity for expected profits from Bakhshi and Gray (2012). However, because only one elasticity is given, a within-group assumption is needed to simulate the underlying elasticities. This is performed on an iterative process in which aggregated elasticities are estimated assuming homogeneity and symmetry.

By the Euler's Theorem, we can assume that the sum of own and cross price elasticities is zero, as shown in equation 5.32 (Chiang, 1984).

Euler's Theorem:

(5.32) $$0 = \frac{\partial A_i}{\partial G_i}\frac{G_i}{A_i} + \frac{\partial A_i}{\partial G_j}\frac{G_j}{A_i} + \frac{\partial A_i}{\partial G_k}\frac{G_k}{A_i} \quad \text{and} \quad 0 = \frac{\partial A_j}{\partial G_j}\frac{G_j}{A_j} + \frac{\partial A_j}{\partial G_i}\frac{G_i}{A_j} + \frac{\partial A_j}{\partial G_k}\frac{G_k}{A_j}$$

In equation 5.33, the within-group assumption assumes that the acreage response for all soybeans is close to the same, regardless of the variety. In equation 5.34, the within-group assumption also assumes that the acreage effects on all soybean varieties from other crops are nearly the same.

Within-Group Assumption:

(5.33) $$\frac{\partial A_i}{\partial G_i}\frac{G_i}{A_i} \approx \frac{\partial A_j}{\partial G_j}\frac{G_j}{A_j}$$

(5.34) $$\frac{\partial A_i}{\partial G_k}\frac{G_k}{A_i} \approx \frac{\partial A_j}{\partial G_k}\frac{G_k}{A_j}$$

When using the within-group assumption with the land constraint, we aggregate the own and cross elasticities from other crops. Equation 5.35 shows the intermediate step of reducing the within-group assumption via Euler's Theorem. The final relationship assumes that the own and cross acreage effects within soybeans must sum to zero, as shown in equation 5.36.

Euler's Theorem and Within-Group Assumption:

$$(5.35)\quad \frac{\partial A_i}{\partial G_i}\frac{G_i}{A_i} + \frac{\partial A_i}{\partial G_j}\frac{G_j}{A_i} + \left(\frac{\partial A_j}{\partial G_j}\frac{G_j}{A_j} + \frac{\partial A_j}{\partial G_i}\frac{G_i}{A_j}\right) \approx 0$$

$$(5.36)\quad 2\frac{\partial A_j}{\partial G_j}\frac{G_j}{A_j} + \frac{\partial A_i}{\partial G_j}\frac{G_j}{A_i} + \frac{\partial A_j}{\partial G_i}\frac{G_i}{A_j} \approx 0$$

The within-group assumption and homogeneity condition derive the elasticity calculation, as shown in equation 5.37. Given equation 5.37, we obtain two unknowns and two equations to solve for the within-group elasticities. In equation 5.37, the cross elasticity, e_{ij} or e_{ji}, is lagged by a year to avoid loops in the calculation. In the next sub-section, we model a substitutability parameter on the cross acreage response soybean elasticities ($e_{ji} = e_{ij}\frac{A_i}{A_j}\frac{G_i}{G_j}$) to simulate how the degree of substitutability between conventional and roundup ready soybeans impacts the simulation results.

Because the elasticities estimated from equation 5.37 do not represent the underlying elasticities in the simulation model and aggregate own and cross acreage effects from other crops. After the model has been simulated, the underlying elasticities in each year are calculated with the simulation model. This is done by calculating the percentage change in acres from a percentage change in the gross margins index for a given year. Because this process is timely, the elasticities in the simulation are only provided for year one, 10, and 19.

Elasticity Calculation:

$$(5.37)\quad e_{ji} = e_{ij}\frac{A_i}{A_j}\frac{G_i}{G_j} \qquad s.t. \quad 0 = 2\frac{\partial A_j}{\partial G_j}\frac{G_j}{A_j} + \frac{\partial A_i}{\partial G_j}\frac{G_j}{A_i} + \frac{\partial A_j}{\partial G_i}\frac{G_i}{A_j}$$

5.1.3 The Degree of Substitutability

In the simulation model, the degree of substitutability is parameterized for conventional and roundup ready soybeans. In many cases, conventional and roundup ready varieties may generate similar gross margins, but have different acreages. Equation 5.38 shows the substitutability constraint, in which the level of substitutability between SPG and private soybeans is defined by λ. This parameter weights the ratio of acres and gross margins by the level of substitutability.

In many respects, the gross margins for a specific crop may be high, such as hybrid fall rye, but the demand is limited. High paying crops like hybrid fall rye may be undesired because of tastes and preferences, which are influenced by factors of weed control, seeding time, storability, and marketability in specific crop regions.

If two varieties were equivalent, the acreage decision should only depend on the gross margins, which results in a proportional acreage response for equal gross margins. This parametric insertion makes it possible to alter roundup ready and conventional cross acreage elasticities depending on whether SPG selects food edible traits ($\lambda = 0$), conventional traits ($\lambda = 0.5$), or biotech traits ($\lambda = 1$). SPG's decision to invest in these traits impacts the degree of substitutability between their soybeans and private roundup ready soybeans.

(5.38) $\frac{e_{ij}}{e_{ji}} = \left(\frac{A_j}{A_i}\right)^{(1-\lambda)} \left(\frac{G_j}{G_i}\right)^{\lambda}$

Where: λ = *the degree of substitutability between SPG conventional and private roundup ready soybeans*

In the simulation, there are three distinct cases as explained above that impact the degree of substitutability:

1. **Low Substitutability:** In the first case, the degree of substitutability between SPG and private market soybeans is zero and SPG selects *food edible traits* ($\lambda = 0$). The ratio of cross acreage elasticities depends only on the ratio of seeded acres, as shown in equation 5.39.

   (5.39) $$\frac{e_{ij}}{e_{ji}} = \frac{A_j}{A_i}$$

2. **Moderate Substitutability:** In the second case, the degree of substitutability is moderate and SPG invests in *conventional traits* ($\lambda = 0.5$). The ratio of cross acreage elasticities depends equally upon the ratio of seeded acres and gross margins, as shown in equation 5.40. In this case, the degree of substitutability in crop traits between conventional and roundup ready soybeans have been slightly relaxed.

   (5.40) $$\frac{e_{ij}}{e_{ji}} = \left(\frac{A_j}{A_i}\right)^{0.5} \left(\frac{G_j}{G_i}\right)^{0.5}$$

3. **High Substitutability:** In the third case, the degree of substitutability is high and SPG invests in *biotech traits* ($\lambda = 1$). The ratio of cross acreage elasticities depends only on the ratio of gross margins, as shown in equation 5.41. When gross margins are the same, the cross elasticities result in proportional changes in acres for conventional and roundup ready soybeans.

(5.41) $$\frac{e_{ij}}{e_{ji}} = \frac{G_j}{G_i}$$

These three cases are simulated to estimate how SPG's decision to invest in certain traits impact welfare and crowding effects over twenty years. The next section of this chapter describes the data and base parameters used in the simulation model. We also explain and estimate the functional form for yield response to investment and the spillover effects between SPG and the private market.

5.2 Data Description and Base Parameters

5.2.0 Base Parameters

The values for all base parameters in the simulation are shown in table 5.0. This sub-section explains the sources and calculations used to obtain the yield, chemical cost, seed cost, acreage elasticity, nitrogen benefit, discount rate, and welfare calculations. The data on how much each player can invest and the yield response to investment is discussed in the next section. Not discussed in this section are the acres, output price, gross margins, and fixed investment rates of each player, which are also shown in table 5.0.

In table 5.0, the entry yield for SPG, quantified by conventional soybeans, is substantially lower than for private roundup ready soybeans. The cost of production for conventional and roundup ready soybeans are also different. Academic research finds that the cost of conventional soybeans, in terms of chemical, is much higher than for roundup ready soybeans. Gaban (2013) finds that under a low weed control level, the cost of herbicide is 8.39 dollars more per acre for variety 5601T (conventional) than for variety Allen (biotech). In the case where farmers desire high weed control and apply higher rates of herbicide, the difference is 12.87 dollars per acre. In the simulation, we calculate the conventional herbicide cost as being equal to 12.87 dollars per acres plus the biotech herbicide costs. An additional pre-burn off application of 3.90 dollars per acre for Heat is added to the herbicide cost for SPG conventional soybeans to control for volunteer canola (Beyond Agronomy, 2010).

The cost for soybean seed depends on the seeding rate, which may vary across farms. In the simulation, we assume that farmers all seed at the same seeding rate. In table 5.0, the seeding rate for soybeans is assumed to be 76.92 pounds per acre, which is equivalent to seeding 200,000 seeds per acre (Saskatchewan Pulse Growers, 2018). Producers are advised by their seed company to seed soybeans at 1.4 bags per acre, a rate of approximately 196,000 seeds per acre

(Heal, 2017). This rate determines the private price of soybean seed at 101.78 dollars per acre assuming a bag costs 60 dollars and seed treatment costs 12.70 dollars per bag (Bergsma, 2017; Heal, 2017; Slobodian, 2017). The cost of SPG conventional seed is 30.77 dollars per acre and is assumed to be the cost of selling seed in the simulation.[1] Importantly, the seeding rate is constant throughout the simulation, and does not change with more productive seed technology.

Table 5.0: Soybean Breeding Investment Simulation Base Parameter Estimates

Parameter	Value	Source
Output Price ($/bu)	10.7	Food and Agricultural Organization of the United Nations (2016)
Roundup Ready Yield (bu/ac)	31.8	Saskatchewan Agriculture (2017)
Conventional Yield (bu/ac)	24.36	Yield Manitoba (2017)
Roundup Ready Seed Price ($/ac)	101.78	Bergsma (2017); Heal (2017); Slobodian (2017)
Conventional Seed Price ($/ac)	30.77	Willms (2018)
Roundup Ready Cost ($/ac)	127.35	Saskatchewan Agriculture (2017)
Conventional Cost ($/ac)	144.12	Saskatchewan Agriculture (2017); Gaban (2013); Beyond Agronomy (2010)
Nitrogen Benefit ($/ac)	35	Saskatchewan Agriculture (2017)
Roundup Ready Gross Margins ($/ac)	146.13	Author's Calculations
Conventional Gross Margins ($/ac)	120.76	Author's Calculations
Other Crop Gross Margins ($/ac)	142.58	Adapted from Statistics Canada (2017b); Saskatchewan Agriculture (2017)
Total Acres	61,166,469	Statistic Canada (2017a)
Roundup Ready Acres	3,035,675	Statistics Canada (2017a)
Conventional Acres	11,794	Yield Manitoba (2017)
Seeding Rate (lb/ac)	76.92	Adapted from Saskatchewan Pulse Growers (2018)
Soybean Acreage Elasticity	2.335	Adapted from Bakhshi and Gray (2012)
Private Discount Rate	0.20	Author's Estimate
SPG Discount Rate	0.05	Author's Estimate
Checkoff Levy (%)	1	Saskatchewan Pulse Growers (2016)
Private Investment (% of profits)	5	Author's Estimate
Number of Private Firms	11	Author's Estimate
Private Profit	204,785,118	Author's Calculations
Farmer Welfare	222,513,727	Author's Calculations
Social Welfare	427,298,845	Author's Calculations

Source: Author

The acreage elasticity in table 5.0 is hypothetical and represents the percentage change in soybean acres from a percentage change in expected soybean gross margins. The acreage elasticity of 2.335 has been scaled by 25 from the pea acreage elasticity estimated in Bakhshi and Gray (2012) because the acreage response for soybeans is assumed to be higher than peas. A sensitivity analysis is conducted on the acreage elasticity in section 5.4 because the parameter is hypothetical and arbitrarily scaled.

[1] SPG sells soybean seed royalty free to producers where the cost of selling seed is assumed to be the conventional seed price.

Additional parameters used in the simulation and their sources are shown in table 5.0. A nitrogen fixation benefit of 35 dollars is included in the gross margins for soybeans. This is added to the gross margins in the simulation and is approximately the average cost of nitrogen fertilizer for cereals and oilseeds (Saskatchewan Agriculture, 2017).

5.2.1 Simulation Model Welfare Estimates

In the simulation model, we calculate private profits, farmer welfare, and social welfare for each year using the partial equilibrium framework as seen in the Methodology section. We estimate the area in the soybean market that represents private profits, farmer welfare, and social welfare for each year. In equation 5.42, net private profits are equal to the price of seed per acre (p) multiplied by the acres of roundup ready seed (A) minus the seed marketing costs (c) and level of investment (C).

(5.42) $\Pi_{j,t} = (p_{j,t} - c_{j,t})A_{j,t} - C_{j,t}$

Where: $\Pi_{j,t}$ = net private market profits per year
$p_{j,t}$ = price of private market soybean seed per acre
$c_{j,t}$ = cost of marketing soybean seed per acre
$C_{j,t}$ = private market level of investment

Farmer welfare only accounts for surplus in the soybean market, as shown in equation 5.43. This equation represents the triangular area that is underneath both SPG and private market soybean seed demand curves and above the seed price (p). Notably, we must solve for the reservation price for each soybean variety, which is the price of seed at zero quantity demanded.

(5.43) $FW_t = (\bar{p}_{i,t} - p_{i,t})\left(\frac{A_{i,t}}{2}\right) + (\bar{p}_{j,t} - p_{j,t})\left(\frac{A_{j,t}}{2}\right)$

Where: $p_{i,t}$ = price of SPG soybean seed per acre
$\bar{p}_{i,t}$ = per period reservation price for SPG soybean seed per acre
$\bar{p}_{j,t}$ = per period reservation price for private market soybean seed per acre

In the simulation model, we assume that farmers do not seed soybeans when their farm profit is equal to zero. Farm profits for SPG and private market soybeans are shown in equation 5.44. Therefore, we estimate the reservation price at the seed price where farm profits are equal to zero.

(5.44) $\pi_{i,t} = P_{i,t}\hat{Y}_{i,t} - w_{i,t}$ and $\pi_{j,t} = P_{j,t}\hat{Y}_{j,t} - w_{j,t}$

Where: $\pi_{i,t}$ = SPG soybean farm profit per acre
$\pi_{j,t}$ = private market farm profit per acre

The cost of inputs for both SPG and private market soybeans are partitioned by the price of seed and the remainder of input costs, as shown in equation 5.45. By this separation, we are able to isolate the seed price when farm profits are equal to zero and solve for the reservation price.

(5.45) $w_{i,t} = p_{i,t} + v_{i,t}$ and $w_{j,t} = p_{j,t} + v_{j,t}$

Where: $v_{i,t}$= remainder of input costs per acre for SPG soybeans
$v_{j,t}$= remainder of input costs per acre for private market soybeans

In equation 5.46, the reservation price is equal to the output price (P) multiplied by the genetic yield index ($\bar{Y}$) minus the remainder of input costs (v).

(5.46) $\bar{p}_{i,t} = P_{i,t}\bar{Y}_{i,t} - v_{i,t}$ and $\bar{p}_{j,t} = P_{j,t}\bar{Y}_{j,t} - v_{j,t}$

In the simulation model, we estimate social welfare simply as private profits plus farmer welfare in each year (equation 5.47).

(5.47) $SW_t = \Pi_{j,t} + FW_t$

In table 5.0, using equations 5.42, 5.43, and 5.47, we calculate private profits, farmer welfare, and social welfare, for the first year of the simulation model. This is calculated with data on the output price, genetic yield index, and input costs. We are unable to calculate following years as this depends on the acreage response elasticities and yield response to investment and spillover rates.

In the simulation model, we estimate the net present value of private profits with the industry standard discount rate of 20 percent. A social discount rate of five percent is used to calculate the net present value of farmer and social welfare. Boardman, Moore, and Vining (2008) find that five percent is an appropriate upper bound discount rate for public projects that have intergenerational impacts and the potential to crowd out private investment.

5.2.2 Genetic Yield Response to Breeding Investment

In the simulation, SPG and the private market increase their soybean yield by investing in breeding. In contrast to the two-stage game, we assume that SPG and the private market have a fixed level of investment. This complements the extensive form game, in which we examine the long-term impact of investment, provided there are investment constraints that are given by how much funds SPG and the private market can realistically allocate to research and development.

SPG's level of investment in soybean breeding depends on the checkoff levy collected from the production of soybeans. The private market's level of investment depends on their percentage of profits allocated to soybean breeding research. The checkoff and percentage of profits used in the simulation are shown in table 5.0.

The yield response to investment has been estimated given data on industry expectations and academic research. From academic research, Rincker et al (2014) uses a statistical approach to estimate the annual change in yield from genetic improvement. The study examines yields from soybeans in maturity groups II, III, and IV across 15 sites in the United States. The cultivars in the study are owned by Monsanto, Syngenta, and Pioneer and use 80 years' worth of data. Results show that the overall yield gains from genetic improvement are approximately 0.3 to 0.5 bushels per acre per year (Rincker et al, 2014).

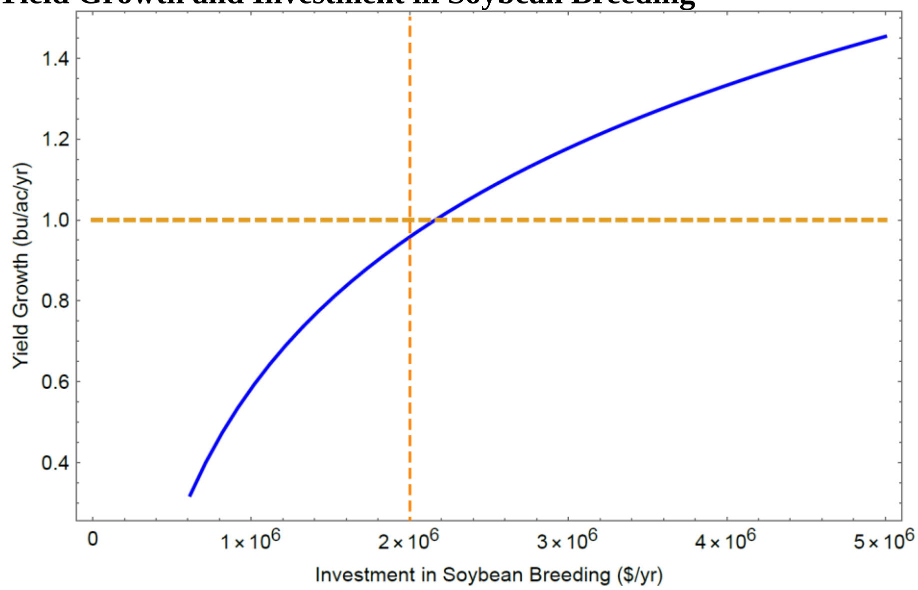
In the simulation, yield response to investment is assumed to be logarithmic form, as illustrated in figure 5.2. Yield gains from breeding research are assumed to level off at higher investment. The logarithmic function provides a benchmark yield response for investment in soybean breeding. In the model, total private investment is divided by 11, which is the number of private firms. These companies include: Monsanto, Dow AgroSciences, DuPont Pioneer, Elite Seeds, NorthStar Genetics, Pride Seeds, Prograin, SeCan, Thunder Seed, Syngenta, and Brett Young Seeds. Notably, Dow AgroSciences and DuPont Pioneer have merged since the simulation was constructed.

In figure 5.2, the logarithmic function is fitted on three data points. The first point is where 500,000 dollars invested per year results in a yield increase of 0.25 bushels per acre per year. Second, one million dollars invested per year results in a yield increase of 0.5 bushels per acre per year. Third, two million dollars invested per year results in a yield increase of one bushel per acre per year.

Although the estimated yield growth in figure 5.2 is high in comparison to the results of Rincker et al (2014), industry breeders believe yield growth rates in Saskatchewan could be the same as yield gains experienced in Manitoba over the past decade (Delheimer, 2018; Lee, 2018). The yield growth from 2001 to 2017 in Manitoba is approximately one bushel per acre per year (Statistics Canada, 2017a).

In the simulation, there is a seven-year lag for when yield gains are realized by SPG and the private market. Ravenscraft and Scherer (1982) assume that it takes roughly three years to develop and release a product after committing to research and development. Alston, Pardey, and Ruttan (2008) state that it takes approximately 5-10 years to breed a new variety. A natural growth rate in the first seven years of the simulation is assumed to be 0.2974 bushels per acre per year, which is the average yield growth rate in Saskatchewan from 2013 to 2017 (Statistics Canada, 2017a).

Figure 5.2: Yield Growth and Investment in Soybean Breeding



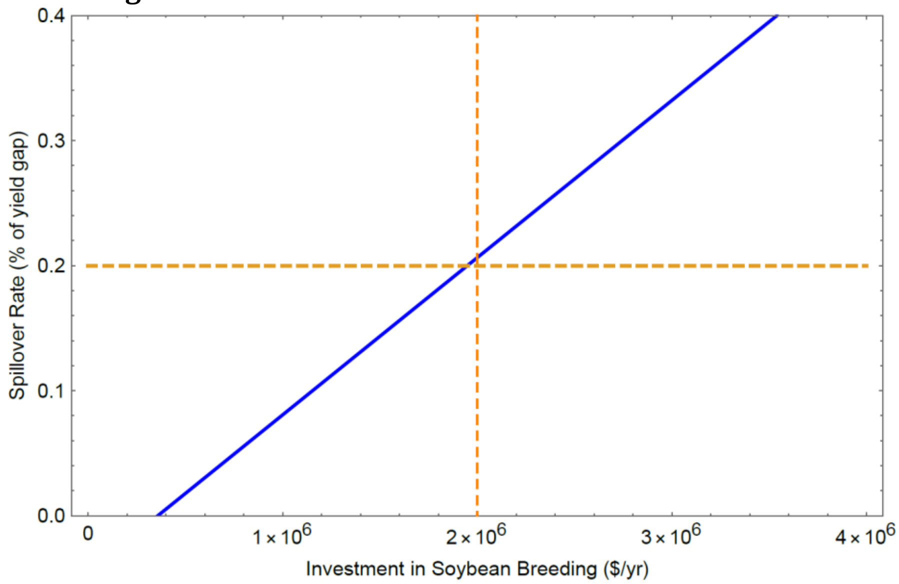
Source: Author

5.2.3 Spillover Effects

In the simulation model, we quantify the research spillovers between SPG and the private market. We assume that research spillovers between SPG and the private market result in yield growth. Breeders acquire better seed technology by reverse engineering their competitor's soybean varieties. This is also permitted in PBR's where rival varieties can be used as a source of initial variation for seed (Plant Breeders' Rights Act, 2015). The only cost to obtain a competitor's knowledge is through investing in soybean breeding, which is like absorptive capacity. However, the spillover effects are only obtained by the player with the lower soybean yield.

The spillover effects are modelled as convergence rates as in Sawka (2014). Sawka (2014) uses the convergence rates to model the narrowing of a percentage gap in lentil production between leading countries and developing countries. In the simulation, spillover effects are calculated as a percentage gap between the difference in SPG and private roundup ready yields. In figure 5.3, the spillover rate is estimated as a linear function of investment in soybean breeding. For two million dollars invested, 20% of the yield gap between varieties is obtained in yield growth for the next year. It is also important to note that only a percentage of this technology is acquired each year, limiting a player's ability to fully realize technology spillovers.

Figure 5.3: Spillover rate as the percentage of yield gap between soybean varieties for investment in breeding



Source: Author

5.3 Simulation Results

5.3.0 Introduction

This section provides the simulation model results, which include the yield, gross margins, yield growth, spillovers, investment, acres, and welfare in each year. Tables 5.1 to 5.6 show the results over twenty years for each case of substitutability. Table 5.7 shows the own and cross acreage elasticities in year 10 for each degree of substitutability. Table 5.8 shows the net present value of private profits, farmer welfare, and social welfare for each degree of substitutability as well.

5.3.1 Case 1 Results

In the case of low substitutability, food edible soybean varieties are assumed to serve a different end-use market than roundup ready soybeans ($\lambda = 0$). The results for case 1 are shown in tables 5.1 and 5.2. Table 5.1 shows the yield and gross margins for both food edible and roundup ready soybeans in all years. Food edible soybean yield surpasses roundup yield in year 20, whereas food edible gross margins surpass roundup ready gross margins in year six. Even with roundup ready yield being higher than food edible yield, the low cost of food edible seed gives food edible soybeans a higher gross margin than roundup ready soybeans. Food edible soybeans also acquire additional yield growth in beginning years from seed technology spillovers from the private market.

Table 5.1: Case 1. Low Substitutable - Yield, Gross Margins, Yield Growth Results for 20 Years of Investment in Soybean Breeding

Year	Roundup Ready Yield (bu/ac)	Food Edible Yield (bu/ac)	Roundup Ready Gross Margin ($/ac)	Food Edible Gross Margin ($/ac)	Roundup Ready Yield Growth (bu/ac)	Food Edible Yield Growth (bu/ac)	PV Spillover Yield Growth (bu/ac)	SPG Spillover Yield Growth (bu/ac)
1	31.80	24.36	146.13	120.76	0.2974	0.2974	0.00	0.57
2	32.10	25.23	149.31	130.05	0.2974	0.2974	0.00	0.58
3	32.39	26.10	152.49	139.42	0.2974	0.2974	0.00	0.57
4	32.69	26.97	155.68	148.70	0.2974	0.2974	0.00	0.56
5	32.99	27.83	158.86	157.85	0.2974	0.2974	0.00	0.53
6	33.29	28.66	162.04	166.75	0.57	0.57	0.00	0.51
7	33.86	29.73	168.16	178.25	0.60	0.60	0.00	0.50
8	34.46	30.83	174.57	190.00	0.62	0.62	0.00	0.49
9	35.08	31.94	181.20	201.89	0.64	0.65	0.00	0.46
10	35.72	33.05	188.06	213.78	0.66	0.67	0.00	0.43
11	36.38	34.16	195.10	225.58	0.68	0.70	0.00	0.39
12	37.05	35.24	202.33	237.19	0.70	0.73	0.00	0.34
13	37.76	36.32	209.86	248.74	0.73	0.78	0.00	0.30
14	38.49	37.39	217.72	260.20	0.76	0.81	0.00	0.25
15	39.25	38.45	225.87	271.52	0.79	0.85	0.00	0.19
16	40.04	39.49	234.32	282.70	0.82	0.89	0.00	0.14
17	40.86	40.52	243.05	293.71	0.84	0.92	0.00	0.09
18	41.70	41.54	252.05	304.59	0.87	0.96	0.00	0.05
19	42.57	42.55	261.32	315.36	0.89	0.99	0.00	0.01
20	43.46	43.55	270.86	326.06	0.92	1.03	0.02	0.00

Source: Author

Table 5.2 shows the results for investment, acres, private profits, and farmer welfare for all years. When SPG selects food edible traits, the growth in their acres increases to a relatively small amount of 98,425 acres. For the private market, roundup ready acres increase to 7.3 million acres after 20 years of investment. Roundup ready acres gain most of the market share in this case even though food edible gross margins are higher. This is due to unappealing characteristics for food edible varieties such as marketability, high agronomic labor, disease resistance, and stress tolerance for geographic regions. This case relates more closely to the current scenario in western Canada where most public varieties are food edible and not substitutable with roundup ready soybeans. For case 1, the change in social welfare over 20 years is approximately one billion dollars.

Table 5.2: - Case 1. Low Substitutable - Investment, Acres, and Welfare Results for 20 Years of Investment in Soybean Breeding

Year	SPG Investment (millions of $)	Private Investment (millions of $)	Other Crop Acres	Soybean Acres	Roundup Ready Acres	Food Edible Acres	Net Private Profits (millions of $)	Farmer Welfare (millions of $)
1	0.97	0.98	58,119,000	3,047,469	3,035,675	11,794	204.8	222.5
2	1.03	1.03	57,962,524	3,203,945	3,188,520	15,425	215.1	239.0
3	1.08	1.07	57,832,736	3,333,733	3,314,250	19,483	223.6	254.1
4	1.13	1.11	57,697,098	3,469,371	3,445,746	23,625	232.4	270.0
5	1.18	1.15	57,581,021	3,585,448	3,557,469	27,979	240.0	284.8
6	1.23	1.19	57,458,559	3,707,910	3,675,686	32,224	248.0	300.5
7	1.32	1.25	57,253,762	3,912,707	3,875,298	37,409	261.4	329.2
8	1.43	1.32	57,024,206	4,142,263	4,099,697	42,566	276.6	361.9
9	1.53	1.39	56,810,145	4,356,324	4,308,282	48,042	290.6	395.2
10	1.64	1.47	56,573,683	4,592,786	4,539,493	53,292	306.2	432.5
11	1.75	1.54	56,351,441	4,815,028	4,756,337	58,691	320.9	470.6
12	1.87	1.61	56,107,971	5,058,498	4,994,792	63,706	336.9	512.8
13	2.00	1.69	55,872,547	5,293,922	5,225,102	68,821	352.5	556.8
14	2.14	1.77	55,610,759	5,555,710	5,482,175	73,535	369.8	606.4
15	2.28	1.85	55,355,932	5,810,537	5,732,249	78,288	386.7	658.0
16	2.44	1.94	55,074,396	6,092,073	6,009,473	82,600	405.4	715.8
17	2.60	2.03	54,798,651	6,367,818	6,280,881	86,938	423.7	776.0
18	2.78	2.12	54,495,631	6,670,838	6,579,990	90,848	443.9	843.1
19	2.97	2.22	54,197,026	6,969,443	6,874,624	94,819	463.8	913.2
20	3.17	2.32	53,870,090	7,296,379	7,197,954	98,425	485.6	990.9

Source: Author

5.3.2 Case 2 Results

In case 2, private market soybeans and SPG soybeans are moderately substitutable meaning that SPG selects a conventional trait that serves the same end-use market as biotech varieties ($\lambda = 0.5$). However, we assume that conventional soybeans are inferior to private market roundup ready technology.

In table 5.3, conventional yield surpasses roundup ready yield in year 19. Conventional gross margins exceed roundup ready gross margins in year six. These results are comparable to case 1 results. Interestingly, the yields and gross margins for both SPG and private soybeans are lower in case 2. This is due to increased competition lowering private profits and investment.

In table 5.4, roundup ready acres increase to 4.9 million by year 20, whereas conventional acres increase to 1.5 million. The change in social welfare over 20 years is 770 million dollars, which is less than the result in case 1. In case 2, farmer welfare is also 120 million dollars lower than case 1 in year 20. In the two-stage game, investing in moderately substitutable traits had the same impact on farmer welfare as less substitutable traits. This suggests that investing in conventional varieties when spillover effects exist reduce farmer welfare.

Table 5.3: Case 2. Moderately Substitutable - Yield, Gross Margins, Yield Growth Results for 20 Years of Investment in Soybean Breeding

Year	Roundup Ready Yield (bu/ac)	Conventional Yield (bu/ac)	Roundup Ready Gross Margin ($/ac)	Conventional Gross Margin ($/ac)	Roundup Ready Yield Growth (bu/ac)	Conventional Yield Growth (bu/ac)	PV Spillover Yield Growth (bu/ac)	SPG Spillover Yield Growth (bu/ac)
1	31.80	24.36	146.13	120.76	0.2974	0.2974	0.00	0.57
2	32.10	25.23	149.31	130.05	0.2974	0.2974	0.00	0.58
3	32.39	26.10	152.49	139.40	0.2974	0.2974	0.00	0.56
4	32.69	26.96	155.68	148.56	0.2974	0.2974	0.00	0.54
5	32.99	27.80	158.86	157.54	0.2974	0.2974	0.00	0.52
6	33.29	28.61	162.04	166.24	0.57	0.57	0.00	0.49
7	33.86	29.67	168.16	177.55	0.59	0.60	0.00	0.48
8	34.45	30.74	174.52	189.07	0.60	0.62	0.00	0.47
9	35.05	31.83	180.95	200.65	0.61	0.64	0.00	0.44
10	35.67	32.91	187.51	212.20	0.62	0.66	0.00	0.41
11	36.28	33.97	194.11	223.63	0.63	0.68	0.00	0.37
12	36.91	35.02	200.81	234.85	0.64	0.71	0.00	0.33
13	37.55	36.06	207.64	245.96	0.66	0.75	0.00	0.28
14	38.21	37.09	214.67	256.93	0.67	0.78	0.00	0.22
15	38.87	38.09	221.82	267.68	0.69	0.82	0.00	0.17
16	39.56	39.07	229.16	278.21	0.70	0.85	0.00	0.11
17	40.26	40.03	236.61	288.47	0.71	0.88	0.00	0.05
18	40.97	40.97	244.24	298.48	0.72	0.91	0.00	0.00
19	41.69	41.88	251.99	308.24	0.74	0.94	0.03	0.00
20	42.46	42.82	260.20	318.34	0.75	0.97	0.06	0.00

Source: Author

Table 5.4: - Case 2. Moderately Substitutable - Investment, Acres, and Welfare Results for 20 Years of Investment in Soybean Breeding

Year	SPG Investment (millions of $)	Private Investment (millions of $)	Other Crop Acres	Soybean Acres	Roundup Ready Acres	Conventional Acres	Net Private Profits (millions of $)	Farmer Welfare (millions of $)
1	0.97	0.98	58,119,000	3,047,469	3,035,675	11,794	204.8	222.5
2	1.03	1.02	57,962,524	3,203,945	3,161,360	42,584	213.3	238.8
3	1.06	1.03	57,864,240	3,302,229	3,202,019	100,210	216.0	251.1
4	1.11	1.06	57,746,020	3,420,449	3,271,489	148,961	220.7	265.7
5	1.15	1.06	57,652,464	3,514,005	3,298,456	215,549	222.5	279.0
6	1.19	1.08	57,543,486	3,622,983	3,352,298	270,686	226.1	294.1
7	1.27	1.11	57,374,747	3,791,722	3,432,048	359,675	231.5	320.5
8	1.36	1.15	57,179,017	3,987,452	3,550,102	437,351	239.5	351.1
9	1.44	1.17	57,002,219	4,164,250	3,629,343	534,907	244.8	382.0
10	1.54	1.21	56,805,634	4,360,835	3,742,371	618,463	252.5	416.5
11	1.63	1.23	56,624,385	4,542,084	3,823,508	718,577	257.9	451.4
12	1.73	1.27	56,427,755	4,738,714	3,935,762	802,952	265.5	489.4
13	1.84	1.30	56,241,404	4,925,065	4,022,710	902,355	271.4	528.6
14	1.95	1.34	56,039,474	5,126,995	4,140,758	986,237	279.3	571.1
15	2.06	1.37	55,846,615	5,319,854	4,236,718	1,083,136	285.8	614.9
16	2.18	1.41	55,640,613	5,525,856	4,362,059	1,163,797	294.3	661.7
17	2.30	1.44	55,442,712	5,723,757	4,467,774	1,255,983	301.4	709.7
18	2.43	1.49	55,233,255	5,933,214	4,601,233	1,331,981	310.4	760.7
19	2.56	1.52	55,030,904	6,135,565	4,716,771	1,418,795	318.2	813.0
20	2.70	1.57	54,808,746	6,357,723	4,862,676	1,495,046	328.0	870.6

Source: Author

5.5.3 Case 3 Results

The simulation results for when SPG and private soybeans are highly substitutable are shown in tables 5.5 and 5.6. In this case, SPG invests in traits that are completely substitutable with private market soybeans ($\lambda = 1$). This means that SPG invests in biotech traits but sells their seed at the conventional price. The effect of SPG increasing their price when they invest in biotech traits is later examined in the sensitivity analysis section.

In table 5.5, when SPG invests in biotech traits their yield surpasses the private market's yield in year 14. In case 3, the private market acquires yield gains from seed technology spillovers in year 14. When SPG has better seed technology, the private market benefits from technology spillovers.

Table 5.5: Case 3. Highly Substitutable - Yield, Gross Margins, Yield Growth Results for 20 Years of Investment in Soybean Breeding

Year	Roundup Ready Yield (bu/ac)	SPG Biotech Yield (bu/ac)	Roundup Ready Gross Margin ($/ac)	SPG Biotech Gross Margin ($/ac)	Roundup Ready Yield Growth (bu/ac)	SPG Biotech Yield Growth (bu/ac)	PV Spillover Yield Growth (bu/ac)	SPG Spillover Yield Growth (bu/ac)
1	31.80	24.36	146.13	120.76	0.2974	0.2974	0.00	0.57
2	32.10	25.23	149.31	130.05	0.2974	0.2974	0.00	0.56
3	32.39	26.09	152.49	139.26	0.2974	0.2974	0.00	0.56
4	32.69	26.95	155.68	148.45	0.2974	0.2974	0.00	0.56
5	32.99	27.81	158.86	157.64	0.2974	0.2974	0.00	0.56
6	33.29	28.66	162.04	166.81	0.57	0.57	0.00	0.56
7	33.86	29.78	168.16	178.80	0.56	0.59	0.00	0.58
8	34.41	30.95	174.11	191.30	0.54	0.62	0.00	0.58
9	34.96	32.15	179.89	204.11	0.53	0.65	0.00	0.55
10	35.49	33.35	185.56	216.98	0.52	0.69	0.00	0.49
11	36.01	34.53	191.13	229.59	0.51	0.73	0.00	0.39
12	36.52	35.65	196.63	241.58	0.53	0.80	0.00	0.26
13	37.05	36.71	202.27	252.94	0.54	0.87	0.00	0.11
14	37.59	37.70	208.04	263.45	0.55	0.94	0.01	0.00
15	38.15	38.63	214.07	273.47	0.57	1.00	0.05	0.00
16	38.77	39.64	220.70	284.22	0.58	1.07	0.10	0.00
17	39.46	40.71	228.07	295.69	0.60	1.13	0.17	0.00
18	40.23	41.84	236.32	307.82	0.63	1.19	0.24	0.00
19	41.10	43.04	245.64	320.61	0.66	1.25	0.33	0.00
20	42.09	44.29	256.22	333.98	0.69	1.30	0.43	0.00

Source: Author

In table 5.6, SPG investment is 6.64 million dollars in year 20. When varieties are highly substitutable, SPG biotech acres are greater than private acres increasing to 9.4 million acres. In year 20, roundup ready acres increase to 5.9 million. When SPG invests in biotech traits, the change in social welfare is over two billion dollars, which is the greatest out of all three investment cases. However, the increase in private profits is greater when SPG invests in food edible traits. This means that the private market's incentive to invest in soybean breeding is reduced when SPG invests in biotech traits.

Table 5.6: - Case 3. Highly Substitutable - Investment, Acres, and Welfare Results for 20 Years of Investment in Soybean Breeding

Year	SPG Investment (millions of $)	Private Investment (millions of $)	Other Crop Acres	Soybean Acres	Roundup Ready Acres	SPG Biotech Acres	Net Private Profits (millions of $)	Farmer Welfare (millions of $)
1	0.97	0.98	58,119,000	3,047,469	3,035,675	11,794	204.8	222.5
2	1.01	0.95	57,962,524	3,203,945	2,943,641	260,304	198.6	236.7
3	1.07	0.92	57,773,670	3,392,799	2,864,149	528,650	193.2	255.2
4	1.13	0.91	57,553,439	3,613,030	2,807,410	805,620	189.4	278.3
5	1.22	0.89	57,304,173	3,862,296	2,757,940	1,104,356	186.0	306.1
6	1.31	0.88	57,026,400	4,140,069	2,727,313	1,412,756	184.0	338.8
7	1.49	0.90	56,550,476	4,615,993	2,790,262	1,825,731	188.2	397.8
8	1.69	0.92	56,024,428	5,142,041	2,860,568	2,281,473	193.0	467.2
9	1.92	0.94	55,446,778	5,719,691	2,925,330	2,794,361	197.3	548.3
10	2.18	0.97	54,821,888	6,344,581	3,009,915	3,334,666	203.0	641.0
11	2.47	1.00	54,158,441	7,008,028	3,101,446	3,906,582	209.2	744.8
12	2.77	1.04	53,474,043	7,692,426	3,225,265	4,467,161	217.6	856.7
13	3.10	1.09	52,765,697	8,400,772	3,374,033	5,026,739	227.6	977.0
14	3.43	1.15	52,052,759	9,113,710	3,569,946	5,543,764	240.8	1,101.6
15	3.79	1.22	51,315,724	9,850,745	3,794,776	6,055,969	256.0	1,234.2
16	4.20	1.31	50,483,875	10,682,594	4,071,818	6,610,776	274.7	1,388.8
17	4.68	1.42	49,538,757	11,627,712	4,392,555	7,235,157	296.3	1,570.6
18	5.23	1.55	48,471,546	12,694,923	4,800,129	7,894,793	323.8	1,782.3
19	5.88	1.71	47,256,427	13,910,042	5,288,495	8,621,546	356.8	2,031.6
20	6.64	1.91	45,881,405	15,285,064	5,915,944	9,369,120	399.1	2,322.4

Source: Author

5.3.4 Overview of Case Results, Elasticities and Net Present Value

The results of the simulation model show that soybean acres in western Canada can be expected to grow by 3.31 to 12.23 million acres in 20 years when SPG and the private market both invest in soybean breeding. This growth rate is not unusual as lentil and pea acres in western Canada have grown by 5.33 million between 2006 and 2016 (Statistics Canada, 2017b). With improved maturity and the ability to seed soybeans in all soil zones, growth in soybean acres should be expected greater than lentils (where lentils are primarily grown on lighter and flatter land).

Table 5.7 shows the own and cross acreage elasticities in year 10. Increasing the degree of substitutability lowers the cross acreage elasticity for private roundup ready soybeans with respect to SPG gross margins (e_{ji}), and increases the cross elasticity for SPG soybeans with respect to private gross margins (e_{ij}). When varieties are perfectly substitutable, this results in a proportional cross acreage change for SPG biotech and private roundup ready soybeans. This effect is achieved by changing the degree of substitutability (λ). The estimated elasticities for each case of substitutability are shown for years one and 19 in tables A.1 and A.2 in the appendix.

Table 5.7: Simulated Own and Cross Acreage Elasticities by Degree of Substitutability (DOS) in Year 10[a]

Elasticity/DOS	λ=0	λ=0.5	λ=1
e_{ii}	2.695	3.46	3.49
e_{ji}	-0.0137	-0.389	-1.29
e_{ki}	-0.00144	-0.0121	-0.142
e_{ij}	-1.274	-0.716	-1.24
e_{jj}	1.303	1.221	4.11
e_{kj}	-0.103	-0.0726	-0.15
e_{ik}	-1.02	-0.747	-1.53
e_{jk}	-0.977	-0.838	-2.1
e_{kk}	0.0794	0.0634	0.21
γ_{ii}	669	10,063	53,559
γ_{ji}	-219	-6,798	-17,884
γ_{ki}	-450	-3,265	-35,675
γ_{ij}	-362	-2,377	-19,058
γ_{jj}	31,522	24,356	56,724
γ_{kj}	-31,160	-21,979	-37,666
γ_{ik}	-450	-3,265	-35,676
γ_{jk}	-31,159	-21,979	-37,666
γ_{kk}	31,609	25,244	73,342

Source: Author

[a] γ represents the change in acres with respect to a dollar increase in gross margins

Table 5.8 shows the net present value of private profits, farmer welfare, and social welfare for each case. Social welfare is discounted at the social rate and accounts for both private profits and farmer welfare. In table 5.8, farmer and social welfare are greatest when SPG selects biotech traits. The net present value of private profits is lowest under high substitutes and greatest when SPG invests in food edible traits. Interestingly, these results are consistent with the two-stage game results where private benefits the most under low substitutability and farmers under high substitutability.

Table 5.8: Simulation Results - Net Present Value of Private Profits, Farmer Welfare and Social Welfare for 20 Years of Investment in Soybean Breeding

	Low Substitutes	Moderate Substitutes	High Substitutes
Degree of Substitutability	0	0.5	1
Private Profits (millions of $)	1,237	1,114	987.7
Farmer Welfare (millions of $)	5,547	5,249	9,037
Social Welfare (millions of $)	9,300	8,354	11,824

Source: Author

The results of the simulation show that the private market is not necessarily crowded out of the soybean market when varieties are high substitutes. However, the private market's incentive to invest in breeding is lowered when SPG invests in biotech traits. The next section conducts a sensitivity analysis to check the robustness of the model and examine how crowding effects are reduced when spillover effects do not exist and when SPG changes their price of seed and level of investment.

5.4 Sensitivity Analysis

5.4.0 Introduction

The sensitivity analysis section checks the robustness of the simulation model by varying the own acreage elasticity for soybeans. This section also examines how crowding effects are reduced when no spillover effects exist for each case of substitutability. This is followed by examining the impact price and investment have on crowding effects and welfare. Lastly, a scenario in which SPG must pay for research as a percentage of their profits is examined.

5.4.1 Acreage Elasticity Effects

Because the acreage elasticity from Bakhshi and Gray (2012) is arbitrarily scaled, a robustness check on the elasticities is conducted. In table 5.9, raising the own acreage elasticity by one percentage point increases the growth in soybean acres dramatically. This is expected because the acreage elasticity quantifies the acreage response to an increase in the gross margins. In contrast, lowering the own acreage elasticity by one percentage point decreases the growth in soybean acres.

Table 5.9: Simulated Parameters for 20 Years of Investment in Soybean Breeding by SPG and the Private Market with Acreage Elasticity Effects

	Low Response	Base Case	High Response
Acreage Elasticity	1.335	2.335	3.335
Degree of Substitutability	1	1	1
Parameter Value in Year 20:			
Private Yield (bu/ac)	41.30	42.09	44.82
SPG Yield (bu/ac)	42.36	44.29	46.63
Private Gross Margins ($/ac)	247.76	256.22	285.46
SPG Gross Margins ($/ac)	313.40	333.98	359.09
Private Reservation Price ($/ac)	349.54	358.00	387.24
SPG Reservation Price ($/ac)	344.17	364.75	389.86
Other Acres	54,288,225	45,881,405	18,661,929
Soybean Acres	6,878,244	15,285,064	42,504,540
Private Acres	3,683,806	5,915,944	18,449,372
SPG Acres	3,194,438	9,369,120	24,055,168
Private Profits (millions of $)	248.5	399	1,245
Farmer Welfare (millions of $)	956.9	2,322	6,952
Social Welfare (millions of $)	1,205	2,722	8,196
Net Present Value:			
Private Profits (millions of $)	979.8	987.7	1,074
Farmer Welfare (millions of $)	5,470	9,037	17,898
Social Welfare (millions of $)	8,048	11,824	21,708

Source: Author

5.4.2 Spillover Effects

Spillover effects in the simulation give the lowest yielding variety yield gains from the better seed technology in the market. In the beginning years of the simulation, SPG obtains yield gains from the spillovers effects. However, as seen in the two-stage game, where there are no spillover effects, farmer welfare is greatest when SPG invests in biotech soybeans and the private market it crowded out. The two-stage game results are consistent in the simulation model. Table 5.10 shows that when SPG invests in biotech traits, farmer welfare is greatest. When SPG invests in food edible traits, the net present value of private profits and social welfare are greatest.

Table 5.10: Simulated Parameters for 20 Years of Investment in Soybean Breeding by SPG and the Private Market with no Spillover Effects

	Low Substitutes	Moderate Substitutes	High Substitutes
Degree of Substitutability	0	0.5	1
Parameter Value in Year 20:			
Private Yield (bu/ac)	44.22	43.22	42.91
SPG Yield (bu/ac)	37.32	36.53	37.20
Private Gross Margins ($/ac)	279.07	268.30	264.98
SPG Gross Margins ($/ac)	259.46	250.93	258.17
Private Reservation Price ($/ac)	380.85	370.08	366.76
SPG Reservation Price ($/ac)	290.23	281.70	288.94
Other Acres	49,833,241	53,963,959	47,982,302
Soybean Acres	11,333,228	7,202,510	13,184,167
Private Acres	11,262,201	6,165,493	6,946,769
SPG Acres	71,028	1,037,017	6,237,398
Private Profits (millions of $)	759.7	415.9	468.6
Farmer Welfare (millions of $)	1,581	957.2	1,726
Social Welfare (millions of $)	2,340	1,373	2,194
Net Present Value:			
Private Profits (millions of $)	1,336	1,203	1,168
Farmer Welfare (millions of $)	6,933	5,468	7,086
Social Welfare (millions of $)	11,481	9,013	10,587

Source: Author

These results show that the private market benefits when there are no spillover effects and SPG invests in food edible traits. If SPG does not want to deter private entry and reduce crowding effects, they could invest in biotech traits that have no spillover effects to reduce competition with the private market. This increases private profits and competition because SPG is unable to acquire yield gains from private market seed technology.

5.3.3 Price Effects

If SPG were to invest in biotech traits, they would likely have to increase their seed price to cover the costs of a licensing agreement with a multinational company (i.e. Monsanto). This section examines the price effects for when SPG invests in biotech traits and raises their price of seed.

In the price effects scenario, gross margins are scaled to the base gross margins. This prevents the percentage change in gross margins from increasing and having a larger impact on the acreage elasticities. If not scaled to the base, SPG biotech acres would increase with higher seed prices as the percentage change in gross margins is higher for low gross margins.

Table 5.11 shows the results for when SPG increases their price of seed. Notably, SPG acres decrease and private acres increase when SPG increases their price of seed. This is expected in our simulation model as higher prices reduce farmers' incentive to purchase SPG soybeans. In table 5.11, the net present value of farmer welfare decreases with higher seed prices. The net present value of private profits is lowest when SPG prices their seed at 30.77 dollars per acre, and highest at the monopolist price (101.78 dollars per acre). These results show that SPG can effectively reduce crowding effects by increasing their price of seed.

Table 5.11: Simulated Parameters for 20 Years of Investment in Soybean Breeding by SPG and the Private Market with Price Effects and Scaled Percent Changes in SPG Gross Margins

	Base Price	Median Price	Monopolist Price
SPG Seed Price	30.77	67.28	101.78
Percent Change Scaling Factor for SPG Gross Margins ($/ac)	0	36.51	71.01
Degree of Substitutability	1	1	1
Parameter Value in Year 20:			
Private Yield (bu/ac)	42.09	42.40	42.61
SPG Yield (bu/ac)	44.29	44.17	43.93
Private Gross Margins ($/ac)	256.22	259.56	261.84
SPG Gross Margins ($/ac)	333.98	296.25	259.11
Private Reservation Price ($/ac)	358.00	361.34	363.62
SPG Reservation Price ($/ac)	364.75	363.53	360.89
Other Acres	45,881,405	47,062,508	49,221,622
Soybean Acres	15,285,064	14,103,961	11,944,847
Private Acres	5,915,944	6,279,308	6,238,893
SPG Acres	9,369,120	7,824,654	5,705,954
Private Profits (millions of $)	399.1	423.6	420.9
SPG Profit (millions of $)	-	285.7	405.2
Farmer Welfare (millions of $)	2,322	1,974	1,556
Social Welfare (millions of $)	2,722	2,683	2,382
Net Present Value:			
Private Profits (millions of $)	987.7	1,032	1,079
SPG Profits (millions of $)	-	1,216	1,753
Farmer Welfare (millions of $)	9,037	7,904	6,748
Social Welfare (millions of $)	11,824	12,087	11,624

Source: Author

5.3.4 Investment Effects

Similar to the price effects scenario, investment effects are examined for when SPG invests in biotech traits. SPG can reduce their level of investment by lowering their checkoff levy percentage invested in breeding. In table 5.12, when SPG lowers their checkoff levy percentage invested in breeding, private soybean acres increase and SPG soybean acres decrease. However, for lower levels of investment, private profits and social welfare increase, while farmer welfare decreases. If SPG invests a 0.1 percent levy into soybean breeding, farmers are less likely to adopt SPG varieties, due to their low gross margins and yield. When SPG invests a 0.5 percent levy into breeding, their acres increase to 8.7 million, whereas private acres increase to 6 million. These results show that SPG can reduce crowding effects by lowering their level of investment in soybean breeding. However, investing only a small portion into breeding has a negative impact on farmer welfare.

Table 5.12: Simulated Parameters for 20 Years of Investment in Soybean Breeding by SPG and the Private Market with Investment Effects

	Base Levy	Moderate Levy	Small Levy
SPG Checkoff Levy (%)	1.0	0.5	0.1
Degree of Substitutability	1	1	1
Parameter Value in Year 20:			
Private Yield (bu/ac)	42.09	42.57	43.69
SPG Yield (bu/ac)	44.29	40.88	26.23
Private Gross Margins ($/ac)	256.22	261.41	273.34
SPG Gross Margins ($/ac)	333.98	297.50	140.78
Private Reservation Price ($/ac)	358.00	363.19	375.12
SPG Reservation Price ($/ac)	364.75	328.27	171.55
Other Acres	45,881,405	46,480,725	48,933,532
Soybean Acres	15,285,064	14,685,744	12,232,937
Private Acres	5,915,944	6,011,715	11,749,417
SPG Acres	9,369,120	8,674,029	483,520
Private Profits (millions of $)	399	405.5	792.6
Farmer Welfare (millions of $)	2,322	2,076	1,640
Social Welfare (millions of $)	2,722	2,482	2,432
Net Present Value:			
Private Profits (millions of $)	987.7	1,121	1,284
Farmer Welfare (millions of $)	9,037	7,589	6,844
Social Welfare (millions of $)	11,824	10,861	11,205

Source: Author

5.3.5 Price Effects with Cost of Investment for SPG

In this scenario, SPG can only invest a percentage of their profits in soybean breeding, as oppose to investing their checkoff levy. SPG acquires profits by pricing their seed higher than the cost of selling seed.

Table 5.13 shows the results for when SPG pays for the cost of investment in breeding with five percent of their profits. When SPG prices seed low at 40.77 dollars per acre, their simulated acres in year 20 increase to 193,526. At this price, SPG's level of investment in breeding is limited, which results in low yield growth and gross margins. SPG can acquire a sizeable market share by increasing their level of investment when they increase their price of seed to 67.28 dollars per acre. The net present value of farmer welfare and social welfare are greatest when SPG prices seed at the median price, as shown in table 5.13. When SPG has to pay for breeding with a percentage of their profits, the net present value of private profits increases under a lower SPG seed price. In this case, SPG invests more in breeding when setting price higher, however, the farmer welfare maximizing price is seemingly below the monopolistic price.

Table 5.13: Simulated Parameters for 20 Years of Investment in Soybean Breeding by SPG and the Private Market with Price Effects and Investment Costs for SPG

	Low Price	Median Price	Monopolist Price
SPG Seed Price	40.77	67.28	101.78
Percent Change Scaling Factor for SPG Gross Margins ($/ac)	10.77	36.51	71.01
Degree of Substitutability	1	1	1
Parameter Value in Year 20:			
Private Yield (bu/ac)	43.73	43.81	46.00
SPG Yield (bu/ac)	25.85	47.34	51.20
Private Gross Margins ($/ac)	273.75	274.59	298.02
SPG Gross Margins ($/ac)	126.67	330.15	336.96
Private Reservation Price ($/ac)	375.53	376.37	399.80
SPG Reservation Price ($/ac)	167.44	397.43	438.74
Other Acres	48,811,165	43,039,204	44,026,894
Soybean Acres	12,355,304	18,127,265	17,139,575
Private Acres	12,161,778	6,827,954	7,871,230
SPG Acres	193,526	11,299,311	9,268,345
Private Profits (millions of $)	820.4	460.6	531
SPG Profit (millions of $)	1.838	391.9	625.2
Farmer Welfare (millions of $)	1,677	2,803	2,734
Social Welfare (millions of $)	2,497	3,263	3,265
Net Present Value:			
Private Profits (millions of $)	1,291	1,137	1,129
SPG Profits (millions of $)	32.12	1,214	2,147
Farmer Welfare (millions of $)	6,877	9,033	8,601
Social Welfare (millions of $)	11,279	12,288	11,882

Source: Author

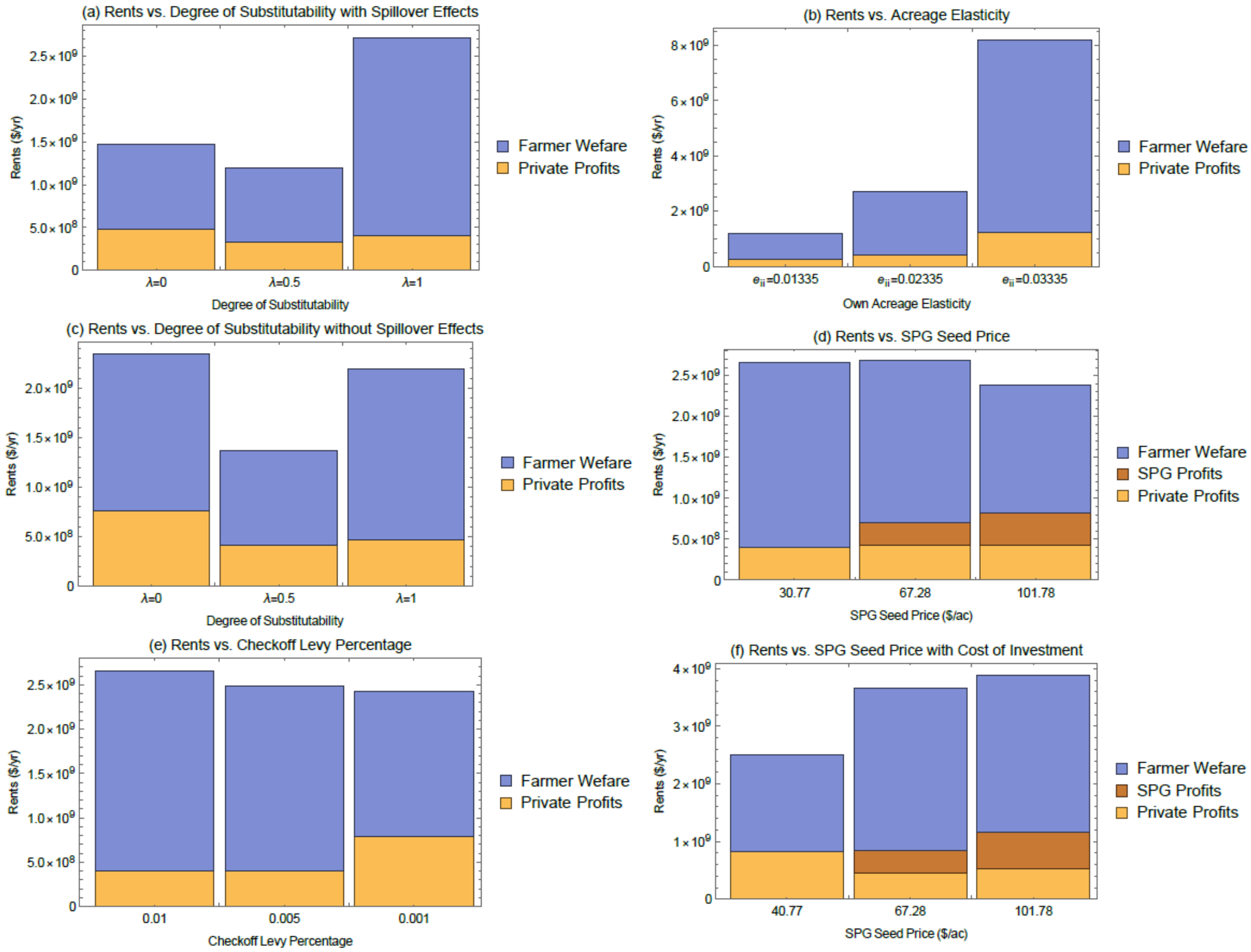
The results of this section show that the private market is less likely to be crowded out when SPG does not use checkoff levies to fund soybean breeding. However, this scenario assumes that SPG can invest more than the checkoff amount. If SPG invests more in checkoff levies as opposed to profits, farmer welfare would be greatest when investing levies.

5.5 Summary and Conclusions

The results of the simulation show that there is a large amount of economic surplus to be gained when SPG and the private market invest in soybean breeding in western Canada. Importantly, the simulation shows that investment in breeding has a large positive impact on stimulating soybean adoption in western Canada. The increase in the soybean genetic yield index increases the gross margins index for soybeans, soybean acres grown, and farmer welfare. These results suggest that there are incentives for private investment in soybean breeding, even when SPG competes and invests in biotech soybeans. Given the size of the soybean market, SPG's investment in soybean breeding captures a sizable portion of the market that would otherwise be allocated to other crops with lower returns. The simulation model shows that farmers benefit the most when SPG invests in biotech traits, prices at a royalty free rate, and invests competitively. In this case, farmer welfare increases by 2 billion dollars or 170 dollars per acre from 20 years of investment in soybean breeding. However, this reduces private profits, which could potentially deter private entry in soybean breeding. The simulation shows that SPG can reduce crowding effects by limiting investment, pricing non-competitively, or selecting traits that are not substitutable with private market varieties. These results are both shown in figure 5.2 and table 5.14.

Figure 5.2 shows the rents in year 20 for all cases and scenarios in the simulation. These results show that farmer welfare in year 20 is greatest when varieties are close substitutes, and when SPG prices and invests competitively. However, this lowers the private market profits in year 20 and lowers the private market's incentive to invest in soybean breeding

Figure 5.2: Simulation Results and Sensitivity Analysis for Private Profits, SPG Profits, Farmer Welfare and Social Welfare after 20 years of investment in soybean breeding in western Canada



Source: Author

Table 5.14 shows simulation results for the Net Present Value (NPV) of private profits, SPG profits, farmer welfare, and social welfare. Similarly, SPG maximizes the NPV of farmer welfare when they invest in biotech traits, and when they price and invest competitively.

The results in figure 5.1 and table 5.14 are relatively consistent and show that when SPG maximizes farmer welfare, they negatively impact the private market. Assuming SPG does not want to reduce private market involvement in soybean breeding, they can reduce crowding effects by increasing their price of seed, lowering their level of investment, and selecting traits that are less substitutable with private market soybean varieties.

The next chapter provides the general summary and conclusions for the thesis findings, some research limitations, and further research.

Table 5.14: Simulation and Sensitivity Analysis Net Present Value (NPV) Welfare Results

Scenario/NPV	Private Profits	SPG Profits	Farmer Welfare	Social Welfare
		(millions of $)		
Substitutability Effects:				
Low Substitutes ($\lambda = 0$)	**1,237**	-	5,547	9,300
Moderate Substitutes ($\lambda = 0.5$)	1,114	-	5,249	8,354
High Substitutes ($\lambda = 1$)	987.7	-	**9,037**	**11,824**
Acreage Elasticity Effects:				
Low Response ($e = 1.335$)	979.8	-	5,470	8,048
Base Case ($e = 2.335$)	987.7	-	9,037	11,824
High Response ($e = 3.335$)	**1,074**	-	**17,898**	**21,708**
Substitutability Effects without Spillovers:				
Low Substitutes ($\lambda = 0$)	**1,336**	-	6,933	**11,481**
Moderate Substitutes ($\lambda = 0.5$)	1,203	-	5,468	9,013
High Substitutes ($\lambda = 1$)	1,168	-	**7,086**	10,587
Price Effects:				
Base Price ($p_{SPG} = 30.77$)	987.7	-	**9,037**	11,824
Median Price ($p_{SPG} = 67.28$)	1,032	1,216	7,904	**12,087**
Monopolist Price ($p_{SPG} = 101.78$)	**1,079**	**1,753**	6,748	11,624
Investment Effects:				
Base Levy (1%)	987.7	-	**9,037**	**11,824**
Moderate Levy (0.5%)	1,121	-	7,589	10,861
Small Levy (0.1%)	**1,284**	-	6,844	11,205
Price Effects with Investment Costs for SPG:				
Low Price ($p_{SPG} = 40.77$)	**1,291**	32.12	6,877	11,279
Median Price ($p_{SPG} = 67.28$)	1,137	1,214	**9,033**	**12,288**
Monopolist Price ($p_{SPG} = 101.78$)	1,129	**2,147**	8,601	11,882

Source: Author's Estimates

Chapter 6 Conclusions

6.0 Thesis Summary

In summary, the thesis findings explain that SPG's investment in soybean breeding benefits farmers where SPG strategically selects traits, pricing, and investment. In western Canada, current soybean breeding investment is set aside by SPG and the private market. By not investing in soybean breeding, economic growth and potential yield gains are foregone.

As a producer-controlled organization, SPG's goal is to invest in research projects that maximize their grower's welfare. General results in this thesis show that investing in soybean breeding program would achieve that goal. However, there is a danger that SPG could crowd out the private market when investing in a soybean breeding program, due to ex post opportunistic behavior. Because private involvement is important to the provincial government, and SPG's operations are delegated by the government, investment decisions for SPG may be limited to strategies that do not interfere with private development. Results from all three models show that SPG has the potential to crowd out the private market under higher competition. SPG can mitigate these risks by selecting investment strategies and reducing competition with the private sector.

The results of thesis can be summarized by the results of each model presented in Chapters 3 to 5. In Chapter 3, the extensive form game shows that SPG entry in soybean breeding could prevent a holdup problem in western Canada by reducing ex post opportunistic behavior. The extensive form game also shows that crowding out is reduced when SPG invests in soybeans that provides research spillovers and increase the private firm's payoff.

In Chapter 4, the two-stage game uses two modelling environments to examine how the degree of substitutability and the difference in the level of existing seed technology crowd out the private firm. The results from the Simultaneous Research game show that when the degree of substitutability is high (SPG invests in biotech traits) and has competitive existing seed technology, the private firm is crowded out. However, when SPG has uncompetitive existing seed technology, they are better off not investing in a soybean breeding program. SPG can reduce crowding effects by selecting food edible traits that are less substitutable with private varieties. The SPG Led Stackelberg game shows that SPG does not reduce crowding effects when they are the first to invest in soybean breeding. However, in both models, SPG can reduce crowding effects by selecting traits that are less substitutable with private firm soybeans.

In Chapter 5, the simulation model provided a full comprehensive analysis by quantifying the effects of investment using data on prices, acres, yield, costs, and acreage elasticities. The simulation derived own and cross acreage elasticities from the multi-output producer surplus function. The results from the simulation show that when SPG invests in biotech traits, they reduce private profits and deter entry. SPG can reduce crowding effects by investing in food edible traits, selecting traits that do not receive technology spillovers from the private market, increasing their price of seed, or lowering their level of investment. When SPG invests in a biotech soybean breeding program, the net present value of farmer welfare is approximately 9.04 billion dollars. If the private market invests, and SPG invests in non-substitutable varieties (such as food-edible), the net present value of farmer welfare reduces to 5.55 billion dollars. For all degrees of substitutability, the change in the net present value of private profits ranges between 988 to 1,237 million dollars.[2]

6.0.0 Policy Implications

In all three models presented in this thesis, SPG's decision to invest in soybean breeding depends much on the degree of substitutability and level of competition with the private market. These investment decisions are explained through the respective model and separated into policy implications. The three investment decisions are:

1. **Invest in Biotech Traits with Large Research Spillovers.** The extensive form game shows that economic surplus in the future is reduced when SPG does not invest in a soybean breeding program. However, SPG has the potential to crowd out the private market when choosing to invest. SPG can reduce crowding effects by providing large research spillovers that benefit the private sector.
2. **Invest in Food Edible Traits.** The two-stage game and simulation model show that when SPG invests in food edible traits, farmer welfare increases primarily in the private market. This decision still benefits farmers as private investment is not deterred.

[2] The net present value of private profits are 988 million dollars when SPG selects biotech traits and 1,237 million when SPG selects food edible traits.

3. **Invest in Biotech Traits with a Moderate Price of Seed and Level of Investment.** In the two-stage game and simulation model, farmer welfare is greatest when SPG invests in biotech soybeans, but this reduces private profits and deters private entry. The simulation model shows that SPG can reduce crowding effects by increasing their price of seed and/or lowering their level of investment in soybean breeding.

6.1 Limitations of Research and Further Research

6.1.0 Research Limitations

The major limitations in this thesis are mainly present in the two-stage game and simulation model. Starting with the two-stage game, using a quadratic production function was a research limitation. In many cases, the degree of substitutability could be parameterized using the Constant Elasticity of Substitution (CES) production function. Other production functions could have been used to model the two-stage game, such as the translog production function. However, these functions do not result in a linear demand system, which increases the complexity of the theoretical model. In the two-stage game, we did not explore research spillovers, joint ventures, or private subsidies, which is a large research limitation. These excluded factors could have been used to attract private investment in the theoretical model.

In the simulation model, a large research limitation was not being able to acquire data on the acreage elasticities in western Canada. The elasticities from Saskatchewan peas were used as a proxy, however, the true value of the acreage elasticity could be very different. The within-group assumption was also a research limitation, which imposed severe restrictions on the simulated elasticities. There could be several methods to estimate the elasticities. However, these methods were out of the scope of my thesis and would potentially require an additional chapter. Another research limitation in the simulation model was defining spillover effects in plant breeding as convergence rates. Spillover effects are usually measured as stock variables that accumulate over time to provide higher technological growth. Changing the functional form for the spillover effects could have a substantial impact on the simulation results.

6.1.1 Further Research

Further research in the two-stage game includes incorporating spillover effects. This would be a challenging endeavor as spillover effects increase the complexity of the two-stage game. In terms of modeling, one could further the investment analysis by examining how pricing of seed impacts welfare in a Hotelling's Model when location is endogenous and represents product differentiation by trait selection.

Further research in the simulation model includes examining the impact of implementing an End Point Royalty (EPR) system in the pulse sector in western Canada. EPRs are a percentage fee on the sale of production that farmers pay to breeders for seed technology. EPRs mitigate the negative effects of brown-bagging through enforcing royalty collection at the end of the supply chain. The impact EPRs have on welfare can be modeled in the simulation as an increase in the price of seed. The impact of increasing the price of seed, as shown in the simulation model, reduces farmer welfare and increases private profits. EPRs may have the potential to increase private profits, which would incentivize innovation and entry in plant breeding. In the long-run, this could increase farmer welfare through a higher level of investment in breeding and higher yield growth in the pulse sector. Whether EPRs benefit both farmers and plant breeders, when compared to other value creation models, is unknown and needs further examination.

Chapter 7 Resources

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Appendix

The appendix shows the calculated own and cross acreage elasticities in year 1 and 19. The calculated elasticities for each case in year 1 are shown in table A.1. In table A.1, elasticities that change with the degree of substitutability are the SPG own elasticity and the cross elasticities between soybean varieties. Table A.2 shows the calculated elasticities for each case in year 19.

Table A.1: Estimated Own and Cross Acreage Elasticities by Degree of Substitutability (DOS) in Year 1 of Simulation

Elasticity/DOS	λ=0	λ=0.5	λ=1
e_{ii}	4.66	34.58	274.4
e_{ji}	-0.00903	-0.125	-1.06
e_{ki}	-0.000473	-0.000473	-0.000473
e_{ij}	-2.33	-2.26	-1.73
e_{jj}	2.34	2.34	2.34
e_{kj}	-0.122	-0.122	-0.122
e_{ik}	-2.75	-2.75	-2.75
e_{jk}	-2.28	-2.28	-2.28
e_{kk}	0.119	0.119	0.119
γ_{ii}	454	3,369	26,733
γ_{ji}	-226	-3,141	-25,508
γ_{ki}	-228	-228	-228
γ_{ij}	-189	-185	-157
γ_{jj}	48,695	48,691	48,663
γ_{kj}	-48,506	-48,506	-48,506
γ_{ik}	-228	-228	-228
γ_{jk}	-48,506	-48,506	-48,506
γ_{kk}	48,734	48,734	48,734

Source: Author

Table A.2: Estimated Own and Cross Acreage Elasticities by Degree of Substitutability (DOS) in Year 19 of Simulation

Elasticity/DOS	λ=0	λ=0.5	λ=1
e_{ii}	2.48	2.37	3.15
e_{ji}	-0.0144	-0.379	-1.31
e_{ki}	-0.00252	-0.0286	-0.428
e_{ij}	-1.27	-0.731	-1.07
e_{jj}	1.3	1.33	4.03
e_{kj}	-0.163	-0.095	-0.262
e_{ik}	-0.651	-0.513	-1.04
e_{jk}	2.36	-0.627	-1.36
e_{kk}	0.301	0.067	0.342
γ_{ii}	-461	10,898	84,528
γ_{ji}	-361	-5,790	-21,581
γ_{ki}	-386	-5,108	-62,947
γ_{ij}	-461	-4,116	-36,235
γ_{jj}	34,284	24,886	86,630
γ_{kj}	-33,823	-20,770	-50,395
γ_{ik}	-386	-5,108	-62,947
γ_{jk}	-33,823	-20,770	-50,395
γ_{kk}	34,209	25,878	113,342

Source: Author